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TRAINING DECISIONS TECHNOLOGY ANALYSIS

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13. ABSTRACT (Maximum 200 words)

The purpose of this project was to examine the proof-of-concept technologies and scientific innovations involved in the Training Decisions System (TDS) Research and Development (R&D) project. Sections one and two of the report provide a history and description of the TDS. Scientific innovations involved in the TDS technology are reviewed in section three. Specific areas discussed include top-down structured systems design and operations research, cost estimation and cost accounting models, allocation and learning curves, and industrial and organizational psychology.

Section four provides an analysis of the potential interrelationships of the TDS technology with other Air Force R&D projects.

The procedures and software from the proof-of-concept TDS were exercised to identify problems in programs and software documentation. Section five details the findings from these exercises. Results indicate the system is operating well and produces detailed and very useful reports and data.

Results of the sensitivity analyses are reported in section six. These analyses were conducted to establish which types of variables had the greatest impact on output products.

Section seven discusses potential applications of the TDS to Air Force training management, the new weapon systems acquisition process, and training decisions technology for other Department of Defense agencies and the civilian sector.

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TABLE OF CONTENTS

Section	Page

TABLE OF FIGURES

TABLE OF TABLES

PREFACE

The Training Decision Technology Analysis (TDTA) is the result of a task order project requested by the Training Systems Division of the Air Force Human Resources Laboratory. The goal of this effort was to examine the technologies developed in the earlier Training Decisions System (TDS) project, to exercise the TDS software and determine the usefulness of previously-developed system documentation, to perform additional sensitivity analyses to establish the significance of various input variables, and to document the relationship of TDS technology with the current state-of-the-art in various scientific disciplines. The work was conducted under Task Number 21 of Contract Number F41689-88-D-0251 with Metrica, Incorporated, San Antonio, TX, as the prime contractor and McDonnell Douglas Missile Systems Company, St. Louis, MO, and the CONSAD Research Corporation, Pittsburgh, PA, as subcontractors.

This volume is the final report of this TDTA project and provides a summary of the work performed to exercise the TDS, improve its software and documentation, and review its relationship to several scientific disciplines. Other major products of this project include:

The TDS User Manual, 1 November 1989 (CDRL A007).

The TDS Programmer Guide, 1 November 1989 (CDRL A007).

TDS Examples, Volumes 1 & 2, 1 November 1989 (to supplement both manuals).

SUMMARY

The Training Decisions System (TDS) is a computer-based decision support technology which has been developed to provide a more integrated approach to Air Force training planning and development. This technology was developed in an earlier research and development (R&D) effort which resulted in a proof-of-concept system. The present project examines the technologies and scientific innovations involved in TDS both from the standpoint of separate subsystem technologies and from the viewpoint of an integrated decision support system. The procedures and software from the proof-of-concept TDS were exercised to identify problems in programs and software documentation; the problems recognized in this exercise were corrected and new programs and data files created. Extensive sensitivity analyses were conducted to establish which types of variables had the greatest impact on output products (total AFS training costs and estimates of On-the-Job Training (OJT) capacity of representative field units. Additional validation work was planned as was a study to examine the systematic biases in TDS data bases. The scientific contributions of the TDS R&D project are examined and some conclusions drawn as to how TDS relates to state-of-the-art technologies in several academic and technical areas. The potential interrelationships of the TDS technology with other Air Force R&D projects are analyzed and several potentially valuable interfaces were proposed. Finally, several potential applications of the TDS technology are recommended in terms of future training management research as well as direct application in other military services and the civilian sector.

TRAINING DECISIONS TECHNOLOGY ANALYSIS

1.0 INTRODUCTION

For nearly two decades, the Air Force has been using the Instructional System Development (ISD) model to guide the design of technical training for enlisted occupations and for support of new weapon system acquisition (see AFR 50-8). The ISD model requires a systems approach to training development, an approach aimed at providing "optimal training" for each specialty or weapon system (AFM 50-2, AFP 50-58). Many of the data elements required for the application of ISD, however, are not readily available in existing Air Force data bases. Further, not all decision algorithms suggested in the ISD model have been empirically validated nor are such algorithms equally applicable to all types of specialties. Decisions involving aircraft maintenance specialties, for example, may require an approach to training decision making that addresses issues which have a direct and immediate impact on combat sortie generation, whereas for a support specialty, the issues may involve primarily the cost per student or student flow limitations.

Recent developments in occupational analysis and training research, as well as in Air Force decision making processes (see AFR 50-8), have created new opportunities for optimizing training. Such developments include the recent emergence of Utilization and Training Workshops (U&TWs) and Training Planning Teams (TPTs) as the primary vehicles for making and coordinating major training decisions (see Mitchell, et al., 1987). Such innovative procedural changes also make obvious a need for a technologically-advanced data generation, analysis, and evaluation capability.

To make good decisions about the training needed for an Air Force specialty or system, decision makers must be able to visualize and understand the jobs and training programs of the specialty or weapon system under consideration and its technical training and Professional Military Education (PME) requirements, as well as the relative costs and payoffs of various training options. Such a "model" provides a concise summary of the current status of the specialty, creates a common "language" for discussion or negotiation, and forms the baseline against which various alternative proposals can be evaluated. Thus, a modeling capability is a very necessary and important element needed for a TDS.

1.1 The TDS R&D Project

To provide adequate support for advanced training decision making, the Air Force Deputy Chief of Staff for Personnel, Education and Training (HQ USAF/DPPE) requested that the Air Force Human Resources Laboratory develop a computer-based Training Decisions System (TDS) to augment the Air Force ISD model. Such a system would generate necessary front-end training requirements data, validated decision algorithms, and procedures for improved interaction among training, personnel, and functional managers. The TDS would focus on supporting Air Force managers in making decisions as to the what, where, and when of the training (including the On-the-Job training) required for a given enlisted specialty (Ruck, 1982).

Over several decades, the Air Force has evolved a task-based approach to determining technical training content and reviewing personnel classification and utilization policies (Christal, 1974; Mitchell, 1988; Morsh, 1964; also see AFR 8-13). As part of the occupational analysis (OA) process, tasks are defined by subject-matter experts (SMEs) of a specialty in their own technical terminology, working with analysts of the USAF Occupational Measurement Center, Randolph Air Force Base, Texas (see AFR 35-2). Several kinds of data on these tasks are collected from job incumbents and supervisors for use in reviewing training programs (see ATCR 52-22). Large samples of incumbents are asked to provide information about which tasks they perform in their present jobs and the relative amount of their job time spent performing such tasks. These data are used to examine the variety of specialized jobs within a specialty (occupation), to assess how jobs change at advanced skill levels, and to review official specialty descriptions and initial training programs (Christal & Weissmuller, 1988; Mitchell, Ruck, & Driskill, 1988).

One of the most important data elements developed during the OA process involves noncommissioned officer (NCO) ratings of tasks in terms of recommended training emphasis for first-term and first-job airmen. Such training emphasis (TE) ratings have been validated empirically using explanatory regression models in studies of 18 AFSs (Stacy, Thompson, & Thomson, 1977; Ruck, Thompson & Stacy, 1987; Ruck, Thompson, & Thomson, 1978). Two important findings of these research studies were that supervisors agreed substantially with one another on their recommendations in most (but not all) career fields, and that supervisors' judgments were explainable in terms of key ISD factors. A third important finding was that supervisors could not agree as to the appropriate sites for training technical tasks. TE ratings are used operationally to evaluate course content of basic technical training courses for first enlistment or first job personnel; typically they are not used to evaluate field training detachment (FTD) or mobile training team (MTT) courses or OJT programs (Mitchell, Ruck, & Driskill, 1988; Mitchell, Sturdevant, Vaughan, & Rueter, 1987; see also ATCR 52-22). Hence, although methods had been developed and validated for prioritizing AFS job tasks in terms of recommended training emphasis for first enlistment personnel, no reliable data were yet available for determining appropriate training setting and site.

By 1980, the determination of training setting was being made at U&TWs, where trainers and training managers met with representatives from operational commands to negotiate training content and training setting (Mitchell et al., 1987; see also ATCR 52-15). These conferences grew out of earlier procedures developed to bring initial skills technical training in line with initial job requirements ("HASTY GRAD" projects), while at the same time planning for those training requirements deferred to FTD, MTT or OJT (Ruck & Birdlebough, 1977; Vaughan, 1978). Only minimal data were available for determining appropriate training settings for specialty tasks; thus, these decisions were, of necessity, based almost entirely upon the conferees' personal experience, or on known constraints at the resident training school. For these reasons, many of the decisions made in U&TWs cannot be consistently replicated. In addition, no formal evaluation or estimates were made of the impact of such decisions on personnel utilization, OJT costs, or mission performance (Ruck, 1982).

The Training Decisions System (TDS) project was initiated by the Air Force Human Resources Laboratory in 1983, at the request of Headquarters, United States Air Force and with the support of Air Training Command, to develop a computer-based, training decision support system to aid Air Force managers in making critical training decisions. The purpose of this research and development (R&D) project was to explore the feasibility of such a system, develop the technologies required to gather, estimate, or process data which could help Air Force managers make more realistic decisions concerning training requirements of a specialty, and to evaluate the possible consequences of such decisions.

The proof-of-concept Training Decisions System (TDS) developed in the initial R&D is a computer-based decision support system which was developed by the Human Factors Branch, Systems Engineering and Analysis Department of McDonnell Douglas Astronautics Company (now the McDonnell Douglas Missile Systems Company), St. Louis, MO, and the CONSAD Research Corporation, Pittsburgh, PA. (with some early participation by the Research Triangle Institute of Research Triangle Park, North Carolina, and some final testing support by the MAXIMA Corporation, San Antonio, TX). This research and development was conducted under AFHRL Contract Number F33615-83-0028 from September 1983 through October 1988. The details of how the system was developed and how it operates are available in a separate technical report (see Vaughan, Mitchell, Yadrick, Perrin, Knight, Eschenbrenner, Rueter, & Feldsott, 1989).

1.2 TDS Technology

The emphasis in the summary report of the initial R&D project was on how the system was developed and its final architecture, processes, and operations. Inherent in that report were a number of new and sometimes innovative technologies which had been developed to meet the needs of a new approach to Air Force training decisions. However, some of these technologies were not very visible in the final report due to the need to summarize five years of development as well as to communicate what the TDS is and what it does.

The details of how these new technologies were developed and the potential scientific contributions of the proof-of-concept R&D were somewhat scattered throughout a series of formal technical reports and papers, draft CDRL reports, technical presentations, and published proceedings of various meetings and conferences.

Given this situation, there was clearly a need to bring together into one document, the evidence of the technologies involved in the TDS and to assess the potential utility of such technologies for the purposes they were designed. Their possible uses in other Air Force R&D projects need to be examined. There was also a need to explore other technologies for potential applications in the TDS as well as any possible refinements of the new technologies from the proof-of-concept system.

The present volume has been developed to help meet such needs. It will review the TDS in terms of technologies used and how they operate. It summarizes a number of tests of the system and identifies a number of refinements which need to be made to make the system more efficient or to enhance its potential applications. It examines how sensitive the TDS is to variations in a number of types of input data and design constraints.

This report also examines the scientific contributions of the TDS R&D in terms of the state-of-the-art of several of the academic and technical areas involved (cost accounting, operations research modeling, learning theory, job and occupational analysis, etc.). This report will also examine some of the potential interfaces of the TDS with other AFHRL R&D projects both from the standpoint of using TDS data in those systems or using new R&D findings in the TDS. Finally, this report examines potential applications of the TDS for use by other military services, federal agencies, and civilian organizations.

To accomplish all these goals, it is first necessary to have some perspective on the various types of technologies involved in the proof-of-concept TDS. The following chapter examines the TDS in terms of each of the TDS subsystems as well as an integrated technology.

2.0 A DECISION SUPPORT SYSTEM FOR AIR FORCE TRAINING DECISIONS

For over two decades, the Air Force has been using the Instructional System Development (ISD) model to guide the design of technical training for enlisted occupations and for support of new weapon system acquisition (see AFR 50-8). The ISD model requires a systems approach to training development, an approach aimed at providing "optimal training" for each specialty or weapon system (AFM 50-2, AFP 50-58). Many of the data elements required for the application of ISD, however, are not readily available in existing Air Force data bases. Further, not all decision algorithms suggested in the ISD model have been empirically validated nor are such algorithms equally applicable to all types of specialties. Decisions involving aircraft maintenance specialties, for example, may require an approach to training decision making that addresses issues which have a direct and immediate impact on combat sortie generation, whereas for a support specialty, the issues may involve primarily the cost per student or student flow limitations.

Recent developments in occupational analysis and training research, as well as in Air Force decision making processes (see AFR 50-8 and AFR 50-23) have created new opportunities for optimizing specialty training. Such developments include the recent emergence of Utilization and Training Workshops (U&TWs) and Training Planning Teams (TPTs) as the primary vehicles for making and coordinating major training decisions (Mitchell, et al., 1987). Such innovative procedural changes also make obvious a need for a technologically-advanced data generation, analysis, and evaluation capability. To make good decisions about the training needed for an Air Force specialty or system, decision makers must be able to visualize and understand the jobs and training programs of the specialty or weapon system under consideration and its technical training and Professional Military Education (PME) requirements, as well as the relative costs and payoffs of various training options. Such a "model" provides a concise summary of the current status of the specialty, creates a common "language" for discussion or negotiation, and forms the baseline against which various alternative proposals can be evaluated. Thus, a modeling capability is a very necessary and important element needed for good decision making. Some type of decision support system is needed to provide information to Air Force decision makers to help them assess potential outcomes of various alternatives.

2.1 Decision Support Systems

Recent technological developments in personal computers, computer networks, and computer-based models have made possible a level of interactive support for decision makers never before possible. A body of literature and theory has developed in recent years in this new area, generated in part by those interested in electronic data processing and computer science and in some measure from those concerned with management science and information systems (Sprague and Carlson, 1982:4) or artificial intelligence and information economics (Keen and Scott Morton, 1978:38-44). Another major influence has been behaviorists concerned with cognitive research (Newell and Simon, 1972; Fleishman and Quaintance, 1984), managerial effectiveness (Campbell, Dunnette, Lawler, and Weick, 1970) or decision strategies for dealing with various levels of uncertainty (MacCrimmon and Taylor, 1976). All of these areas have been integrated into modern decision support technology.

2.1.1 Key Concepts of Decision Support Systems

Decision support for management decision making implies the use of computers to:

1. Assist managers in their decision processes in semi-structured tasks.

2. Support, rather than replace, managerial judgment.

3. Improve the effectiveness of decision making rather than its efficiency.

(Keen and Scott Morton, 1978:1)

Systems designed to provide support for decision making are generally called Decision Support Systems (DSS) which are very different from the traditional record keeping and transaction processing uses of computers (Sprague and Carlson, 1982:xiii). A DSS can be defined as follows:

> "A DSS is a coherent system of computer-based technology (hardware, software, and supporting documentation) used by managers as an aid to their decision making in semistructured decision tasks. We stress *supporting* rather than *replacing* managerial judgments (Bennett, 1983:1)."

The key concepts involved in computer-based support for executive decision making were first developed by M. S. Scott Morton in the early 1970's who, at that time, termed them "management decision systems" (Scott Morton, 1971). The DSS label has become more widely used during the later 1970's and early 1980's (Keen and Scott Morton, 1978:1). DSSs are said to be typically "*interactive* computer-based systems which *help* decision makers utilize *data* and *models* to solve *unstructured* problems. The unique contribution of DSS resulted from the key italicized words (Sprague and Carlson, 1982:4)." These authors note that few actual systems completely satisfy this rather restrictive definition. They go on to say that a DSS may be defined by its capabilities in several critical areas, including the following:

> "They tend to be aimed at the less well structured, underspecified problems that upper-level managers typically face.
>
> They attempt to combine the use of models or analytic techniques with traditional data access and retrieval functions.
>
> They specifically focus on features that make them easy to use by noncomputer people in an interactive mode.
>
> They emphasize flexibility and adaptability to accommodate changes in the environment and decision-making approach of the user."

(Sprague and Carlson, 1982:6)

In examining the use of computers to support various types of decision making, Bennett (following the ideas of Anthony about planning and control systems) classifies decisions into the following four categories:

> **Strategic planning:** decisions relating to setting policies, choosing objectives and selecting resources.
>
> **Management control:** decisions related to assuring effectiveness in acquisition and use of resources.
>
> **Operational control:** decisions related to assuring effectiveness in performing operations
>
> **Operational performance:** decisions that are made while performing the operations.
>
> (Carlson, 1983:16)

Gorry and Scott Morton have been concerned with the degree to which decisions were structured or unstructured; they combined Anthony's categories with the dimension of structure to develop a four by four matrix of decision categories (Gorry and Scott Morton, 1971). In describing their approach, Carlson notes that, "almost no computer support is used for unstructured decisions. They argue that the semi-structured and unstructured decisions (especially management control and strategic planning) are of the greatest concern to decision makers (Carlson, 1983:16)". Decision Support Systems are designed to assist managers with such semi-structured and unstructured types of decisions, while more structured decisions (such as budget analysis) are serviced by management information systems (MIS). Some authors consider DSSs as a subset of the broader MIS classification.

2.1.2 Critical Characteristics of DSSs

DSSs have high potential value for managers and other decision makers, yet there have been only a few actually successful applications of computer-assisted decision support systems in government and business, although there are a good number of effective management information systems. Based on a review of recent citations in the PsycLIT Abstracts (APA), some of the more successful applications of DSS have been in academic administration, library science, R&D management, program evaluation, small group assisted decision making, and strategic planning. Many more are proposed than are successfully implemented. DSSs sometimes fall into disuse or are misused either because of manager's concerns over loss of responsibility. The reliability of data (because of defensive reporting, cognitive biases, or fear of responsibility) is sometimes a problem which can result in abandonment of the DSS unless suitable reliability control methods are developed (Zakay, 1982).

Alter (1980) reports a survey of fifty-six DSSs which seemed to fall into two broad categories: data-oriented systems and model-oriented systems. Data-oriented systems are characterized by data retrieval, analysis, and presentation functions, whereas model-oriented systems use simulation or optimization models to help managers and executives make more effective decisions. Both of these types of functions or capabilities are needed if decision makers are to make use of the full potential of the integrated DSS approach. These functions were developed to parallel the processes observed in manual decision making.

In reviewing studies on decision making in order to specify realistic DSS requirements, Carlson (1983:20) concluded that there are a variety of decision making processes so that a DSS must be able to support multiple processes. He also notes that different types of decisions have different data and processing requirements so that a DSS must be flexible in order to support various types of decisions.

Keen and Scott Morton observe that a DSS approach has potential impact as follows:

> a. The impact is on **decisions** in which there is sufficient structure for computer and analytic aids to be of value but where managers' judgement is essential.
>
> b. The **payoff** is in extending the range and capability of managers' decision processes to help them improve their effectiveness.
>
> c. The relevance for managers is the creation of a **supportive tool, under their own control**, which does not attempt to automate the decision process, predefine objectives, or impose solutions.
>
> (Keen and Scott Morton, 1978:2)

Thus, to be an effective tool, a DSS must be flexible in terms of the types of decisions which it can support and must be carefully designed so that direction of the system is under the control of the user. The user must specify the questions to be addressed and the DSS must be able to provide the data in whatever form that can be used most effectively by the user. In this regard, Carlson (1983:20) reviewed the literature to identify the attributes or characteristic needs of decision makers and made the following observations:

> 1. Decision makers rely on conceptualizations in making a decision, and a DSS should provide familiar representations (e.g., charts and graphs) to assist in conceptualization.
>
> 2. Decision makers perform Intelligence, Design, and Choice activities while making a decision, so a DSS should provide operations which support these activities.
>
> 3. Decision makers need memory aids, so a DSS should provide memory aids which help carry out the decision-making process.
>
> 4. Decision makers exhibit a variety of skills, styles, and knowledge, so a DSS should help decision makers work in their own idiosyncratic ways.
>
> 5. Decision makers expect to control their decision support, so a DSS should provide control aids which help decision makers exercise direct, personal control.

From these observations, Carlson concluded that representations are a key focus of an effective DSS. The system needs to assist managers in developing their conceptualization of the problems so as to reflect as close as possible the real world issues and constraints. This might be done through charts or graphs or whatever other type of display a manager is comfortable using so long as it incorporates the significant variables on which realistic decision are to be made. For group decision making, such "modeling" of reality also needs to extend the decision makers' understanding of the problem (multiple perspectives, multiple criteria) by serving as a memory aid for complex data bases (available for recall as needed).

Odiorne (1984) observes that key decision makers also need to be better motivated by the organization; they need to be treated in some respects as "stars." A DSS can do this in a nonintrusive way, by demonstrating a considerable investment on the part of the organization in collecting information, building data bases, and providing a complex decision support system to help or assist its key decision makers.

Thierauf (1982), in discussing the ten essential characteristics of a DSS, observes that the system must take a broad-based approach to supporting decision making, with an emphasis on managing by perception. By this he means that a DSS must take a broader view of the organization and must be forward looking; decision makers' judgments are absolutely critical for understanding future external and internal trends. The complex threads of such trends must be assimilated in the context of competing or alternative probable decisions (on long term organizational goals, focus of marketing, etc.). He also suggests that a DSS must make use of appropriate mathematical and statistical models in a flexible way. By making use of on-line computing capacity and flexible models, managers can insert their own assumptions about key characteristics or issues; multiple runs are made to assess outcomes under a variety of conditions or assumptions. He states, "Thus, instead of a single optimum result from the model (as in MIS), several outputs are obtained to answer 'what if' questions. This enables solutions to be judged by managers on a variety of criteria, including risk, robustness, and performance (Thierauf, 1982:67)."

Other requirements noted by Thierauf include: output directed to organizational personnel at all levels; integrated subsystems; comprehensive data base; easy-to-use approach; and an adaptive system over time. These are "essential characteristics" of an effective DSS (Thierauf, 1982:61-76) which permit it to meet the needs of organizational decision makers. Since his essential characteristics are critical to the design of an effective DSS, they are recapped in Figure 2.1 on the next page.

Sprague and Carlson (1982) also call for flexibility in both building at DSS and in its employment. They urge an interactive design and creation of an adaptive system which can be modified in use to better meet the needs of its users or new sets of decision makers (Sprague and Carlson, 1982:139-144). They also suggest user tutorials to enhance the ability of decision makers to employ the system as well as an evaluation and tracking system which can provide needed information to improve the system. Their view is that these processes and mechanisms can provide a flexibility for a DSS which is missing from most traditional management information systems and thus greatly enhances the probability that the DSS can and will be used for effective decision making. They assert that such flexibility must encompass both the level of technology and the time horizon for change (Ibid:145).

1. **Broad-based approach to supporting decision making – accent on "management by perception."** Decision support systems go beyond capabilities of a typical management information system by taking a broad view of the organization in terms of supporting decisions. They utilize "management by perception," whereby managers are assisted in perceiving important future trends and helped in adapting the organization to upcoming conditions.

2. **Human/machine interface where human retains control over the decision-making process.** The utilization of CRT terminals gives the decision maker the capability to retrieve, manipulate, present, and store data such that there is a human/machine dialogue during decision making. Throughout the interface, the decision maker has complete control over all stages of the decision-making process in solving a problem.

3. **Support decision making for solving structured, semistructured, and unstructured problems.** Generally, the focus is on semistructured and unstructured decisions although well-structured decisions can also be made in a DSS environment. Basically, DSS recognizes the need for bringing together human judgment and computerized information for improving the quality of the final decision.

4. **Utilization of appropriate mathematical and statistical models.** Based on the needs of the problem being solved, one or more mathematical and/or statistical models are employed to assist the decision maker in evaluating alternative solutions. The real payoff from mathematical and statistical models as well as modeling languages comes from integrating them into the decision support system as decision tools.

5. **Query capabilities to obtain information by request – interactive mode.** In DSS, query capabilities go beyond those of interactive computation and include those of responsiveness. The latter item refers to utilizing the system as an extension of the individual's reasoning process throughout the decision-making process.

6. **Output directed to organization personnel at all levels.** Although DSS has the capability to supply top and middle management with important short- to long-range planning information for decision making (that was not available with earlier computer systems), it is also capable of providing lower management and their operating personnel with the necessary output for supporting decision on controlling current operations.

7. ***Integrated subsystems.*** This concept refers to the capability of processing data for use by all subsystems along broader, functional lines rather than the traditional, narrow departmental lines. Integrated subsystems allow managers and their personnel to retrieve and manipulate information of concern to them for supporting decisions.

8. **Comprehensive data base.** Contents of the data base for DSS must go beyond just providing historical information about current and past operations. It must also contain appropriate external information that is compatible with internal information contained in the data base. Generally, it is desirable to utilize a data base management system (DBMS) to assist in a human/machine dialogue.

9. **Easy-to-use approach.** The hallmark of effective DSS is that it is easy to use, that is, not only does it assist the decision maker in supporting decisions via a human/machine interface, but also allows the individual to pursue his or her own natural tendencies to problem solving. From this view, the individual feels comfortable and "at home" with the system rather than intimidated by it.

10. **Adaptive system over time.** The main thrust of the adaptive system concept is that the decision maker is able to confront changing conditions and adapt the system to meet these changes. The time factor for effecting system changes is a few weeks to several months.

<u>Figure 2.1</u> Essential Characteristics of Decision Support Systems. (Adapted from Thierauf, 1982:Figure 3-8,78)

2.1.3 Potential DSS Design Issues

Moore and Chang have noted that there are potential problems in designing an effective DSS, "given the organizational and technological constraints inherent in any computer-based development effort (Moore and Chang, 1983:173)." These include the issue of system or problem migration, where both system design and problem understanding shift over time. Another potential issue is subset evolution; this involves expanding of system capabilities over time to match the decision maker's changing preferences and increasing capacity to use the system. There is also some conflict between "soft" versus "hard" DSS capabilities where initial, generalized capabilities are increasingly specified by designers or users so as to become very specific ("hard") system functions. A final issue involves a weak-strong design continuum; a weak design follows users' current preferences where a strong design deliberately attempts to shape and refine the users' decision-making process (Ibid.:174). Each of these issues requires some consideration on the part of DSS designers and specific choices must be made in terms of practicality for a given organization and with due regard for cost (development time, equipment, etc.). Further, controversy over these and other operational concepts often make it difficult for systems designers to construct a simple practical system since typically too many optional capabilities are thought to be desirable.

These authors maintain that the most popular concepts involving DSS (such as improving "managerial effectiveness") are not very helpful for a DSS designer. They have developed an alternative framework for DSS design including a new definition of a DSS:

> Decision Support System (DSS) - an extensible system with intrinsic capability to support **ad hoc** *data extraction, analysis, consolidation and reduction*, as well as decision-modeling activities. For example, a general ledger-based planning system with both preformatted and user-definable reports or forecasts (loosely interpreted as models) is a DSS.
>
> (Moore & Chang, 1983:179)

Inherent in this definition is the recognition of the need for a DSS to evolve over time as users learn how to make use of the system and system designers learn more about how decision makers can use models, data summaries, and alternative analyses to improve their decision making processes. In this respect, it is expected that there will be a synergistic effect where successful implementation of a DSS will generate a body of information about advanced decision making which will lead to further R&D not just to improve the DSS but also which will lead to new decision support technologies.

Zachary takes this approach a step further and maintains that a DSS must be designed so as to extend the cognitive skills of its user. He believes that, in general, decision support technology has developed more rapidly than its theory; he views a DSS as an interface between the cognitive processes of its user and a set of underlying computation algorithms. For his perspective, a DSS is defined as: "any interactive system that is specifically designed to improve the decision making of its user by extending the user's cognitive decision-making abilities (Zachary, 1988:998)."

He goes on to note that,

> "it must do more than simply place information within the reach of the decision maker, hoping that such access will somehow assist decision making. ... A DSS is intended to remove some obstacle or relax some constraint that is preventing the human decision maker from making the best possible decision."
>
> (Zachary, 1988:998)."

In this context, Zachary notes that most decision support systems are situation specific and "there are few (if any) generic systems. Virtually all are tied to a specific decision problem, decision environment and/or class of decision maker and specific class of difficulties/constraints affecting it/them (Ibid.)."

Recognizing these facts, he contends that DSS design must focus on two major components - the human-computer interface (HCI) and the decision-aiding algorithms. The decision-aiding algorithms produce all the information that is displayed and the user never sees the data structures, inference algorithms, optimization programs or other procedures. "As far as the DSS user is concerned, the interface is the system (Zachary, 1988:999). Both areas are important parts of a DSS, and this author notes a number of specific design issues which must be considered in designing such a system (such as selecting automated analysis and reasoning techniques, representation aids, judgement refinement and amplification tools, etc). He concludes by calling for a "Human-Aided Optimization" to deal with complex, non-linear functions, so as to maximize the strengths of both computer systems and experienced human decision makers (Ibid.:1028).

2.1.4 Future R&D Requirements

While one primary focus of any future training decision technology R&D will obviously be directed toward improving the system-user interface, a major possibility is the evolution of the system toward an Artificial Intelligence (AI) technology. Gorry and Krumland (1983) have anticipated this line of development and suggest that AI research has already had an impact on DSS technologies and designs. In discussing the contribution of artificial intelligence research to DSS, they note that:

> The recognition of the importance of knowledge in problem solving has sharpened the study of the intellectual topography of problem domains. The study of the knowledge involved in tasks such as analyzing a scene or understanding a sentence has in turn stimulated the development of representational schemes and new programming languages for the organization and marshaling of different kinds of knowledge in problem-solving programs. In this way, a range of problems are being attacked with renewed vigor in the field.
>
> (Gorry and Krumland, 1983:216-217)

These authors conclude that a theory of knowledge will eventually be of concern to DSS designers as it is to AI researchers, and that the continued development **ad hoc** decision systems will eventually accumulate information necessary for the development of a comprehensive theory of knowledge. They do believe that AI technology can and should be applied in advanced DSS applications.

In reviewing recent DSS development approaches, Stabell (1983) cautions that the focus of new DDS approaches must focus on **decisions** (the D in DSS). He writes,

> It is the **decision** in the concept that should define the unique context of DSS, and the **decision** should have implications for the why, how, and what of building such systems. However, in much of the literature I find that the decision is not really in focus. In many discussions very little would be altered if we were to exchange the decision label for another term (management, executive, personal, mind, or whatever).
>
> (Stabell, 1983:223)

He recommends a dual focus in future R&D efforts not only to develop enhanced DSS technologies but also to study decisions themselves and how the decision process works and changes across time. His approach to developing a DSS is summarized in Figure 2.2. He recommends a "decision-oriented approach" where a second major focus is on research on the decisions themselves and suggests that this impacts on DSS design and development processes. Only by such a dual thrust can substantial long-term progress be made in improving not only decisions being made but the decision-making process itself.

Another major area of possible R&D is that of Utility Analysis. Most research of utility models has concentrated on the efficiency of personnel selection algorithms (c.f., Blum & Naylor, 1968; Boudreau & Rynes, 1985). In recent years, however, utility analysis has also been applied in the evaluation of training programs, with an emphasis on the gain in productivity of trained versus untrained workers (c.f., Schmidt, F.L., Hunter, J.E., & Pearlman, 1982). There is some question, however, as to the impact which such utility analysis efforts have had. Zedeck and Cascio observe that

> An unfortunate myth that has developed among many business decision makers is that employee selection methods and other behavioral science-based organizational interventions have had little impact on workforce productivity, in part because statistical indices of utility have had little impact on decision makers. Like it or not, the language of business is dollars, not forecasting efficiency, r^2, or improved performance in terms of standard deviation.
>
> (Zedeck & Cascio, 1984:490-491)

In their review of personnel decisions, these authors note that utility analysis has considerable promise, particularly since it is now possible to translate the outcomes of personnel decisions (including training) into dollars, the common metric for business. They caution, however, that the issues are generally more complex than present utility models might suggest. They cite Boudreau's (1983) concern that current utility models do not recognize the economic effects of variable costs, corporate taxes, and discount rates.

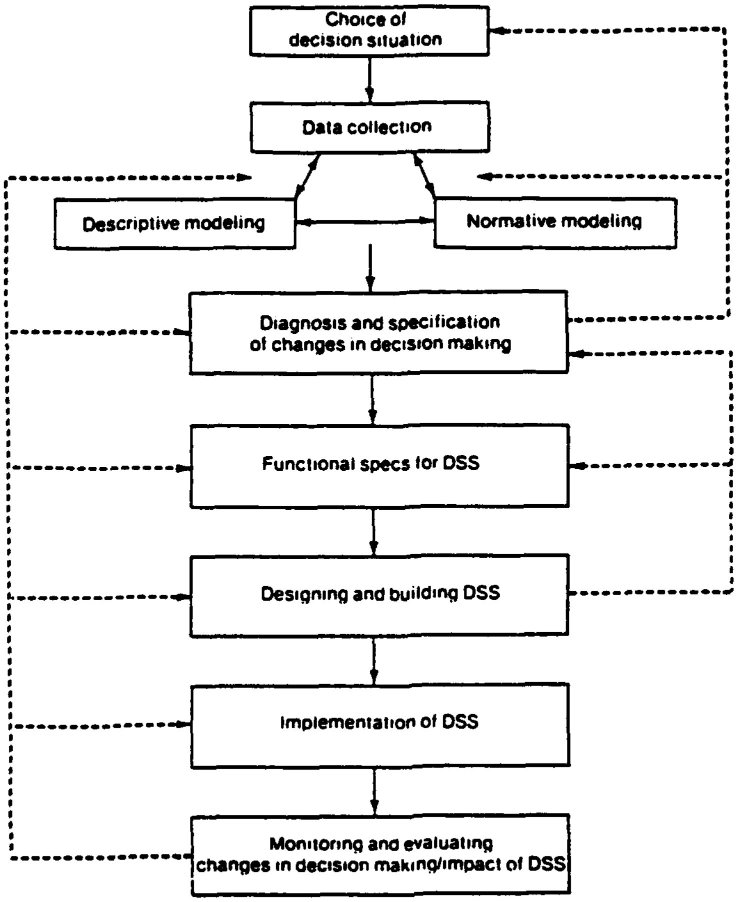


Figure 2.2 **Decision-Oriented DSS Development Process (From Stabell, 1983:234).**

Some researchers have extended the Schmidt, et al. approach to take into account the factors of concern to Boudreau. Mathieu and Leonard, for example, report development of a "time-based" approach which corrects utility estimates to account for such economic considerations (Mathieu & Leonard, 1987). Their methodology permits examination of the total dollar savings resulting from training for periods ranging from one to twenty years in the future. They also built into their model the capability to vary potentially significant variables and assumptions; for example, they were able to assess alternative assumptions - one where the effectiveness of training remains constant over time and an alternative where there is a 25 percent decay in training effectiveness per year (Ibid.:327, Table 4).

Others, such as Becker (1989), have become increasingly concerned that while utility analysis can now "more accurately measure the costs and benefits of human resources programs, both in the present and the future" ... "conventional utility models have ignored the effects of the external labor market on estimated utilities (Becker, 1989:531)." He concludes that failing to consider such factors generally overstates the likely utility of the programs being evaluated.

If such labor market factors are also to be accounted for in a utility model in addition to the economic factors of Boudreau and time variance (Mathieu & Leonard), such utility models quickly become extremely complex and the results difficult to analyze and understand. Many of these factors or assumptions may be interactive. As Zedeck & Cascio observed:

> So far, theoretical developments in this area have outpaced practical applications. One theoretical question that should receive greater empirical attention in different organizational contexts is the relationships among the utilities of selection, training, and other organizational interventions. As Schmidt, et al. (1982b) and Landy, et al. (1982a) have noted, they may be interactive or additive, depending on such parameters as the selection ratio, selection validity, and SD_e. To be sure, these questions need to be addressed in the context of an overall personal decision system.
>
> (Zedeck & Cascio, 1984:493)

In a more recent review of training-related psychological research, Latham (1988) takes a fairly critical approach to utility analysis. He states:

> Little has appeared on the utility or cost effectiveness of training programs per se. It may be noteworthy that the economists themselves have not embraced this methodology as advocated by psychologists. What is troublesome about work in this area is that the standard deviation of performance in dollars is almost always based on a primitive estimate (Landy et al., 1982). Dreher & Sackett (1983) have taken a skeptical view by pointing out that (a) there is no evidence that a rational estimate approach to assessing the standard deviation of performance approximates the true value; (b) agreement among job experts is not a guarantee that the estimates are valid; and (c) the procedure lacks face validity in that the basis of each supervisor's judgment is unknown. As is the case with performance appraisal (Latham, 1986), the question arises of who in the organization is requesting information on the monetary value of conducting in-house training programs? More appropriate may be to ask "What does upper management take into account when determining the value of ... training?"
>
> An implicit assumption is that, having conducted a utility analysis, a company will eliminate fewer personnel programs (e.g. training) during an economic hardship than it would have before. This assumption needs to be tested. The reason why Brogden & Taylor's (1950) work on the dollar criterion has been largely ignored for 38 years may be that the customer has not asked for it.
>
> (Latham, 1988:560-561)

This alleged lack of interest on the part of managers and decision makers may stem from the lack of context (i.e., framework of total training costs) or the absence of an adequate decision support system (tools to assist in decision making) rather than any disregard for potential dollar savings. As noted in the introduction, some $30 billion a year is spent on formal training and approximately $180 billion on on-the-job training (ASTD, n.d.). Much of the informal OJT costs are hidden costs, which are not normally visible to managers. Yet formal training programs have their greatest impact by avoiding such OJT costs by providing more most-effective, centralized training. Any improvement in the management of OJT has the potential for significant savings and substantially enhanced productivity.

In order for a manager or decision maker to come to realistic decisions, any DSS must first provide the decision maker with a good perspective on current training programs and their costs, including the normally invisible OJT requirements and costs. Once such a baseline is established (context, if you will), the decision maker can then more properly assess the real magnitude or impact of any new or proposed training program.

At present, utility analysis is probably not yet at a stage where most of the important variables and assumptions have been adequately researched or their interactions understood. The many functions and their interactions are extremely complex and are probably beyond the capabilities of most decision makers, without some decision support. As further R&D is accomplished on utility analysis (UA), on the human decision making process, or on decision support technologies, the research findings may be mutually beneficial. Indeed, as realistic DSSs are developed and their real world applications effected, then we may find that the essential elements of UA can be extended to include a much more realistic set of problems and data.

Future TDS R&D efforts may well represent such an opportunity for the further UA R&D since it involves large number of people and training programs, high levels of cost, and real public policy issues which could benefit from improved decision making.

2.1.5 The TDS as a DSS

Clearly, the problems faced by most Air Force training decision makers are much the same as those encountered by many civilian executives in business and public service. The kinds of information needed before realistic decisions can be made and the varying levels of specificity involved are typical of the types of issues faced by designers of most decision support systems. Many of the modeling techniques and conceptualization procedures developed in recent years through DSS R&D efforts should be directly applicable in facing the complex issues involved with Air Force training programming and planning. Most of the lessons learned by DSS developers are relevant for Air Force decision making as well.

For this review of the technology involved in the TDS, one of the issues to be examined is how the TDS R&D effort relates to the typical development process for a DSS. What does the DSS literature and recent theoretical developments imply for the implementation and future R&D for TDS? What are the accomplishments of the TDS R&D in terms of implications for the DSS area?

Before we can begin to answer these questions, we need to first briefly review the TDS project to develop an overview of what the project was designed to do and how it accomplished its stated requirements. In this review, the emphasis will be on explicating the various technologies used to meet the needs of this R&D project, and how these technologies relate to the corresponding academic disciplines. In addition, we must examine how this project relates to other on-going Air Force R&D efforts.

2.2 The TDS R&D Project

To provide adequate support for advanced training decision making, the Air Force Deputy Chief of Staff for Personnel, Education and Training (HQ USAF/DPPE) requested that the Air Force Human Resources Laboratory develop a computer-based Training Decisions System (TDS) to augment the Air Force ISD model. Such a system would generate necessary front-end training requirements data, validated decision algorithms, and procedures for improved interaction among training, personnel, and functional managers. The TDS would focus on supporting Air Force managers in making decisions as to the what, where, and when of the training (including the On-the-Job training) required for a given enlisted specialty (Ruck, 1982).

Over several decades, the Air Force has evolved a task-based approach to determining technical training content and reviewing personnel classification and utilization policies (Christal, 1974; Mitchell, 1988; Morsh, 1964; also see AFR 8-13). As part of the occupational analysis (OA) process, tasks are defined by subject-matter experts (SMEs) of a specialty in their own technical terminology, working with analysts of the USAF Occupational Measurement Center, Randolph Air Force Base, Texas (see AFR 35-2). Several kinds of data on these tasks are collected from job incumbents and supervisors for use in reviewing training programs (see ATCR 52-22). Large samples of incumbents are asked to provide information about which tasks they perform in their present jobs and the relative amount of their job time spent performing such tasks. These data are used to examine the variety of specialized jobs within a specialty (occupation), to assess how jobs change at advanced skill levels, and to review official specialty descriptions and initial training programs (Christal & Weissmuller, 1988; Mitchell, Ruck, & Driskill, 1988).

One of the most important data elements developed during the OA process involves noncommissioned officer (NCO) ratings of tasks in terms of recommended training emphasis for first-term and first-job airmen. Such training emphasis (TE) ratings have been validated empirically using explanatory regression models in studies of 18 AFSs (Stacy, Thompson, & Thomson, 1977; Ruck, Thompson & Stacy, 1987; Ruck, Thompson, & Thomson, 1978). Two important findings of these research studies were that supervisors agreed substantially with one another on their recommendations in most (but not all) career fields, and that supervisors' judgments were explainable in terms of key ISD factors. A third important finding was that supervisors could not agree as to the appropriate sites for training technical tasks. TE ratings are used operationally to evaluate course content of basic technical training courses for first enlistment or first job personnel; typically they are not used to evaluate field training detachment (FTD) or mobile training team (MTT) courses or OJT programs (Mitchell, Ruck, & Driskill, 1988; Mitchell, Sturdevant, Vaughan, & Rueter, 1987; see also ATCR 52-22). Hence, although methods had been developed and validated for prioritizing AFS job tasks in terms of recommended training emphasis for first enlistment personnel, no reliable data were yet available for determining appropriate training settings and sites.

By 1980, the determination of training settings was being made at utilization and training workshops (U&TWs), where trainers and training managers met with representatives from operational commands to negotiate training content and training settings (Mitchell et al., 1987; see also ATCR 52-15). These conferences grew out of earlier procedures developed to bring initial skills technical training in line with initial job requirements ("HASTY GRAD" projects), while at the same time planning for those training requirements deferred to FTD, MTT or OJT (Ruck & Birdlebough, 1977; Vaughan, 1978). Only minimal data were available for determining appropriate training settings for specialty tasks; thus, these decisions were, of necessity, based almost entirely upon the conferees' personal experience, or on known constraints at the resident training school. For these reasons, many of the decisions made in U&TWs cannot be consistently replicated. In addition, no formal evaluation or estimates were made of the impact of such decisions on personnel utilization, OJT costs, or mission performance (Ruck, 1982).

2.2.1 Approach

The general strategy used in developing the Training Decisions System focused on first defining functional requirements and then developing the structure, methodologies, and procedures for meeting those requirements. The research team collected as much information as possible concerning Air Force training decisions and how they were made; a variety of agencies and offices were visited to define the desired functions and data requirements of the system (Mitchell, Sturdevant, Vaughan, & Rueter, 1987).

Based on the information gathered from such visits and a review of the previous research literature, the following types of variables were determined to be particularly important for Air Force decision makers and thus must be represented explicitly within the TDS:

- o Tasks of the Specialty and Their Associated Characteristics
- o Task Allocations to Training Settings
- o Managers' Preferences for Task Allocations to Training Settings
- o Times Required to Training Tasks in Various Setting Allocations
- o Utilization and Training Patterns, in terms of:
  - Jobs & Associated Tasks
  - Training States
  - Transition Probabilities Among Jobs and Training States
  - Numbers of Airmen in Various Training and Job States
  - Airman Proficiency States
- o Training Costs
- o Training Resource Requirements
- o Training Capacities
- o Managers' Preferences for U&T Patterns

Some data on the tasks, jobs, and training states are generally available from existing sources, such as the occupational analysis program or course documentation. For other variables, few if any data are available in existing Air Force data bases. For example, data concerning OJT costs are not routinely available, and innovative approaches were required to develop such information for use by training decision makers.

A preliminary integrated systems design was developed to guide the R&D effort which provided for a set of subsystems to deal with the three broad, relatively independent classes of data (task information, training and job patterns, and costs versus training capacity constraints) plus a fourth subsystem to integrate such data and display it for decision makers. The preliminary system design was validated and refined through interactions with potential Air Force users (Vaughan, Yadrick, Perrin, Cooley, Dunteman, Clark, & Rueter, 1984).

The general approach used in TDS development was to start from known data bases, such as the OA report files or personnel flow statistics, and to develop new data gathering technologies to determine, estimate, or approximate other required information. Where possible, an evaluation of alternative approaches was conducted; several methods were initially tested and the method yielding the best results was adopted for use in the TDS. Where necessary, experimental designs were employed when it was necessary to verify method effects or analyze data differences. Generally, data collection and analysis methods were developed on two Air Force specialties (Avionic Inertial and Radar Navigation Systems, AFS 328X4, and Security and Law Enforcement, AFS 811XX), and were later validated and refined on two additional specialties (Electronic Computer and Switching Systems, AFS 305X4, and Aircraft Environmental Systems, AFS 423X1).

Such development and testing was done in a systematic, integrated way to insure that the various types of information could be synthesized into a coherent picture of the various ways training requirements of a specialty could be met and the relative cost of each alternative. The objective was to make visible to specialty managers and training staff officers their decision options, as well as the constraints and relative cost consequences of each decision.

At periodic intervals throughout the TDS development project, the research and development team briefed their progress and results to an Air Force TDS advisory panel, which included representatives of HQ USAF, HQ Air Training Command, the USAF Occupational Measurement Center, functional specialty managers, and training managers. Such periodic progress reviews were extremely constructive in terms of constructive critique of results and positive interaction between researchers and potential system users. Suggestions were made for needed design improvements, data displays, new data sources to be evaluated, or other possible solutions to research and development problems. As a result of such interactions, a separate plan was developed to guide the transition of TDS from an research and development project to an operational system in an appropriate Air Force organization; this transition plan was circulated to various Air Force agencies and offices for coordination and staffing (Vaughan, Yadrick, Perrin, Mitchell, Sturdevant, Rueter, & Ward, 1985). The end result of such interactive progress reviews was an improved systems design and TDS products which should be much more useful to potential TDS users.

2.2.2 Subsystem Technologies in the Proof-of-Concept TDS

The initial research and development of the TDS has been completed. The proof-of-concept system consists of three interdependent subsystems which deal with Task Characteristics, Field Utilization pattern modeling, and Cost/Resource data generation, as well as a fourth Integration and Optimization subsystem (see Figure 2.3). This section of the report will present a conceptual overview of the system to provide a general perspective of the TDS and a basic understanding of its structure and operation. For the purposes of the present report, a short description of each subsystem and it development should suffice.

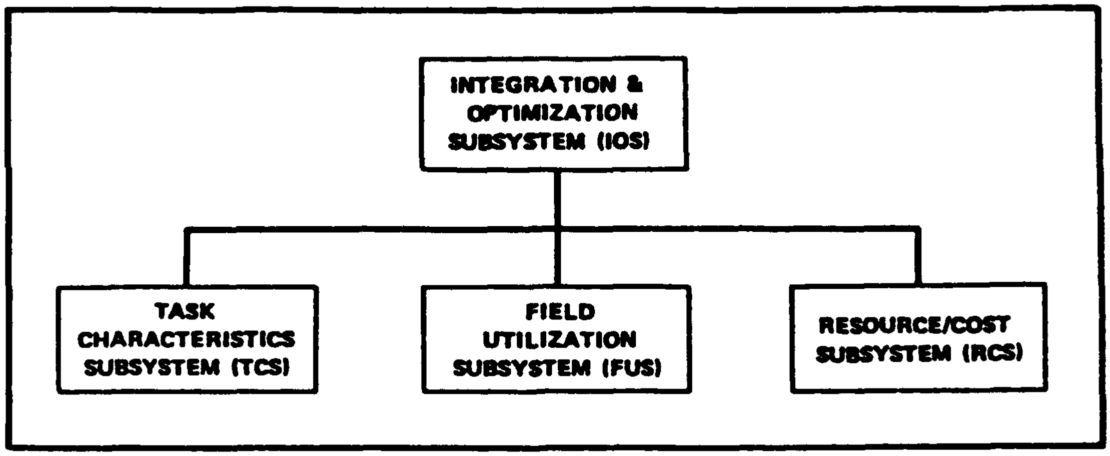


Figure 2.3. Major Subsystems of the Training Decisions System

2.2.2.1. Task Characteristics Subsystem (TCS) Technologies

The TCS embodies two separate technologies dealing with tasks and groups of tasks; one involves grouping of tasks and the second allocates these groups of tasks to training settings.

The Task Module (TM) is a grouping of tasks which can serve as the basic unit of analysis in the TDS. TMs solve a number of problems associated with the use of task-level data (see Perrin, et al., 1987). As noted earlier, the Air Force presently makes some use of task-based data for training decisions; one problem is that many tasks share a common skill and knowledge base and thus much task-level information may be redundant for training decision making. TM-level data, reflecting shared skills and knowledges, reduces the possibility of redundancy and overestimating training requirements. A second part of the problem in using task data is the fact that each specialty involves 300 to 2,000+ tasks, far too many for managers to process in a typical U&TW session. Indeed, U&TW participants generally focus on review of the relevant Specialty Training Standard (STS) topics or areas, leaving detailed review of tasks to occupational analysts and training developers.

According to some interpretations of the ISD literature, in order to fully understand and classify all the tasks of a specialty in terms of their common skills and knowledges, a detailed task analysis would be required on every task before any decisions about training could be made. The fact is that task analysis is an exceedingly time-consuming, labor-intensive, expensive process, and various types of tasks may require differing types of analysis (DeVries, Eschenbrenner, & Ruck, 1980; Eschenbrenner, DeVries, Miller, & Ruck, 1980). The Air Force probably cannot afford the manpower and expense of a detailed task analysis for every task of every specialty. Therefore, a procedure is needed to group or cluster tasks which share common skills and knowledges; i.e., those tasks which could be trained together most efficiently.

Task Clustering Techniques. In TDS, individual tasks are grouped into clusters of related tasks called Task Modules (Perrin, Vaughan, Yadrick, Mitchell, & Knight, 1986). Advanced Comprehensive Occupational Data Analysis Programs (CODAP) procedures were used for hierarchical clustering of tasks and interpretation of meaningful clusters of tasks on the basis of task co-performance. It was found that the help of subject matter experts (SMEs) was critical to naming the modules, assessing their significance in terms of common skills and knowledges (i.e., groupings of tasks which can be effectively trained together), and allocating isolated tasks which did not statistically cluster. The final procedure was a combined approach using statistical co-performance clustering to form initial groupings of tasks, having an analyst identify task groupings which appeared meaningful, and then having SMEs title and refine the task groupings into TMs. This approach saves time for both analysts and SMEs and provides a structured focus for their efforts (see Perrin et al., 1986 for details).

Allocation Functions. A second TCS technology involves the development of Allocation Curves as a mechanism for translating between hours of training provided and the degree of required proficiency achieved for each Task Module in each type of training setting.

Once TMs are finalized, survey instruments are developed to gather information as to how TMs are or should be allocated to various training settings. Groups of senior technicians in the specialty, who are familiar with the work of the specialty, estimate how much training time is currently devoted to reach minimum required proficiency for the various groups of tasks for the following training settings: classroom, correspondence courses such as career development courses (CDCs), hands-on training (FTDs, MTTs, etc.), supervised hands-on experience on the job (OJT), and other programs. These raters also provide training time estimates for "ideal" training (i.e., the most effective mix of types of training). Finally, the raters are asked how long it would take in each setting to train the TM, if the training was provided in only that setting (e.g., only classroom training, etc.). This "maximum effective training" may not always yield full proficiency; it may not be possible to fully train a TM in one or more of the settings alone. In such cases, respondents indicated the proficiency level reached as a percent of full proficiency. Thus, each SME provided six allocation judgments for each TM: four that related the maximum training time in each of four settings to the proficiency level reached, one for the current allocation, and one for the most preferred allocation of training.

What Is Proficiency? For TDS, proficiency was defined as a percentage of the training needed by an average individual to reach the minimum required standard for each TM (the "go/no go" level of OJT = 100% proficiency). SMEs generally understood and were able to estimate degrees of proficiency expressed in this way. SMEs are also able to reliably and consistently describe the current training pattern in terms of how training in each type of setting contributes incrementally to the attainment of full proficiency (i.e., the partial proficiency achieved). They also easily conceptualized other combinations of training for reaching the same goal (i.e., alternative training allocations). Because these combinations vary systematically, they can be expressed as mathematical functions.

It was hypothesized that proficiency gain from training in a setting would be greatest initially and would decline as more training was provided in that setting. Eventually, there would be no more gain from providing training. Thus, the predicted relationship between proficiency and time in a training setting is that of initial gain followed by proficiency leveling-off; a negatively accelerated curve. This general set of relationships is depicted in Figure 2.4; these curves are theoretical estimates to illustrate the expected relationships. The relationships can also be expressed in the following polynomial regression equation:

$$\text{Proficiency} = a * \text{class-hours} - b * \text{class-hours}^2 + c * \text{self-study-hours} - d * \text{self-study-hours}^2 + e * \text{field-training-hours} - f * \text{field-training-hours}^2 + g * \text{work-hours} - h * \text{work-hours}^2,$$

where "a" through "h" are coefficients to be estimated by multiple regression, ^{2} indicates squaring, and the regression equation is constrained to pass through the origin (there is no constant for the Y intercept).

This model involves specific hypotheses about the nature of the relationship between setting training hours and proficiency. Specifically, controlling for training in each of the

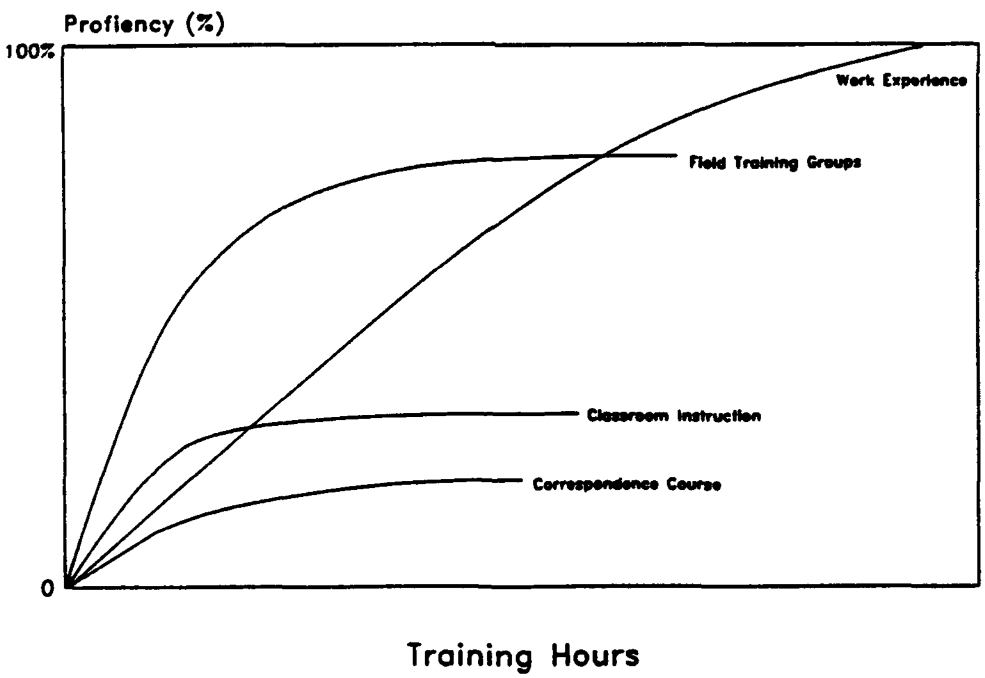


Figure 2.4. Hypothesized Relationship Between Hours of Training in a Setting and Proficiency Gain (from Perrin et al., 1988:29).

other training settings, the first-order parameter is specified to be positive and the second-order parameter is negative, yielding the predicted negatively accelerated curve. Across the four AFSs studied during TDS development, this statistical model was strongly supported. Statistical estimates consistent with the polynomial regression equation were found in well over 90% of the allocation curves in all four specialties (Perrin et al., 1988).

There are two additional sources of support for the conceptualization of proficiency gain as a negatively accelerated function of training time in a setting. First, the overall fit of the polynomial regression model was found to be quite good, averaging over 65% (multiple R^2) in two specialties. Second, the additional variance explained by the second- order terms in the allocation equations was substantial (approximately 15% increase in R^2 for these two specialties), indicating that simple linear functions are not sufficient to describe proficiency gains from training in each setting (see Figure 2.5 for an example allocation curve). As noted in the report of our research and development of the TCS, a curvilinear model is much more descriptive of these relationships (Perrin et al., 1988).

Possible alternative allocations range (theoretically) from training everything about a TM in the classroom to training the TM entirely on the job. (In reality, it is likely that complete proficiency can only be achieved through a combination of training programs; only in OJT could 100% of the required proficiency be achieved in a single setting.) By collecting data from SMEs on a few possibilities (i.e., current, "ideal," and "maximum effective" training) and on the time involved for each, allocation curves are generated which represent all possible combinations. Such curves permit a direct translation among settings of training time to percent of required proficiency for each TM, thus facilitating specification and evaluation of training alternatives (i.e., various combinations of training times in different settings that, in total, achieve 100% of the required proficiency).

Allocation curves for all TMs of a specialty derived through this survey approach give the TDS maximum flexibility in considering different ways of dividing training among training settings, as well as identifying the limits of each type of training. In addition, by asking SMEs to provide information on "ideal" and "maximum effective" training times in the various settings, we are able to evaluate the limits of effective training for any given setting, independent of any training in the other settings. [As additional training settings are identified, they could be added to the data collection effort, and to the AFS data base; the only limitation is on the number of settings SMEs can rate realistically.]

This capability serves as the foundation for developing and evaluating alternative patterns of training (as will be discussed in the Field Utilization Subsystem section). Thus, the allocation curves are a very significant part of the overall TDS design. Their development and validation represent a substantial advance in training decisions technology, although it is obvious that further empirical validation of these relationships is also needed.

The set of TMs developed for a specialty represents one of the major building blocks of the TDS. The TMs are a major input to the Field Utilization Subsystem (FUS) and serve as the basis for describing jobs and training states (courses, OJT programs, etc.). Data are summarized or averaged to the module (TM) level, such that jobs can be described

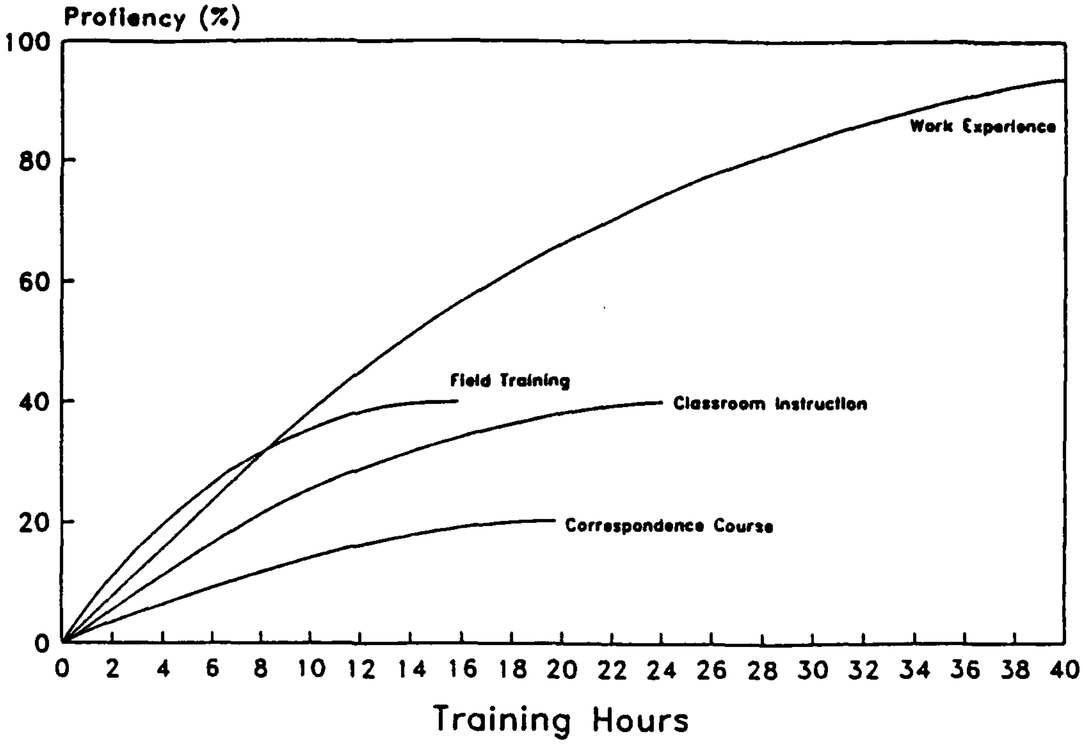


Figure 2.5. Example Allocation Curves for Aircraft Environmental Systems (AFS 423X1) TM 34, Doppler Sensor Control Boxes.

in terms of percent of job incumbents performing each TM and the total time spent on TMs. Training course content is also expressed in terms of hours of training per TM. Thus, training and job content descriptions (and data files) share a common set of terms. The TMs also serve as a foundation for the Resource/Cost Subsystem (RCS) in that information about training resources required and available are collected on a TM basis. This greatly reduces the complexity of required RCS data collection and the statistical prediction of training costs and capacities.

2.2.2.2 Field Utilization Subsystem (FUS) Technologies

The FUS provides information for defining training and job assignment patterns and collecting management preference values for the current and several plausible alternative approaches to training, assigning, and utilizing airmen in a particular specialty over the span of their Air Force careers (see Vaughan, et al., 1989; Yadrick, et al., 1987). This complex area required the development of several new technologies in order to meet the needs of the system.

FUS Flow Simulation Program: A Dynamic Modeling Approach. A computer-based simulation program was developed for TDS as a tool to facilitate analysis of current and alternative U&T patterns, and to permit calculation of total specialty training requirements for each pattern. Such a simulation program is absolutely necessary for the TDS if we are to model and evaluate changes to any of the variables used to characterize specialty jobs, job content, training programs, course content, assignment probabilities, training capacities of units, and training costs or resources.

The dynamic simulation program is a major innovation in technology in terms of better estimation of OJT requirements for all jobs in the specialty. It considerably extends earlier research aimed at adapting econometric and manpower modeling to the issues of personnel assignment flows and training costs in operational units (Eisele, Bell, & Laidlaw, 1978; Rueter, Bell, & Malloy, 1980). Such a simulation is critical for calculating OJT requirements, costs, and realistic representative unit training capacities; any changes in job content, training programs, or even assignment probabilities have an impact either directly or indirectly on the requirement for OJT.

The program is a dynamic simulation system which processes descriptive data files in such a way as to show total numbers of personnel flowing through jobs and training programs over an extended period of time. Data can be examined by any specified period of time; training flows are generally expressed as annual rates where assignment probabilities are more realistically portrayed for two or three year intervals equivalent to the typical Air Force specialty job assignment. Such dynamic processing of several models (U&T patterns) of a specialty provides the needed flexibility to project future requirements and assess the consequences of proposed changes.

Existing computer-based simulation programs, such as the Simulation Language for Alternative Modeling (SLAM), were found to be not fully adequate for handling the complex specialty models to the degree needed in the TDS. Several systems were examined and tested but were found to be unable to handle the complexities of most Air Force specialties (Yadrick et al., 1987). Thus, new simulation software had to be designed and tested which would meet the specific requirements of the TDS.

Modeling an Air Force Specialty

In the TDS, once an analyst has defined a set of task modules (TMs) for an occupation and collected data on training setting allocations, these data are then used to describe all training courses and jobs in a relatively concise way. A static picture of the jobs and training programs is not enough, however, to capture the dynamics of the normal flow of reassignments of people from one job to another, nor to assess the probability of receiving advanced technical training or professional military education (Mitchell et al., 1988). Considerable training is made necessary by such reassignments; the amount varies dramatically depending on the prior training and experience of the individual and the type of equipment (system or mission) in place at new locations. The TDS integrates assignment probability data with job and training data into a dynamic model for the occupation, and employs a simulation program to estimate total hours of training required for each TM for each person in all courses and on-the-job training (OJT) programs. This paper provides an overview of the job and training pattern simulations used to quantify total training requirements.

A description of the current U&T pattern for a given occupation is a necessary starting point for understanding the current situation and for developing possible management alternatives. Appropriate data must be synthesized from a variety of sources--most notably from TI/CODAP occupational survey (OS) data, personnel records, training management data files, the training catalogue (AFR 50-5), TDS surveys, and informal interactions with functional managers, training staffs, and field supervisors--to gain a comprehensive perspective on the occupational area.

A key element in defining career patterns is the identification of jobs within an occupation. In occupational analysis terminology, "job" refers to a group of related positions in which many of the same tasks are performed; "position" refers to a unique set of tasks performed by one person (Shartle, 1959). Each occupation includes a number of jobs that vary in content according to organizational level, assigned functions, equipment operated or maintained, level of experience of personnel, and a number of other interrelated factors (Driskill & Mitchell, 1979; Vaughan 1978).

For the TDS, major job types are identified using standard OA methods for analysis of data collected from job incumbents (Archer, 1966; Christal, 1974; Christal & Weissmuller, 1988; Cragun & McCormick, 1967; Mitchell, Ward, & Driskill, 1989). The OA job types provide a realistic foundation for describing the current U&T pattern for Air Force enlisted occupations, although some issues remain regarding the level of analysis most appropriate for the TDS (Yadrick, et al., 1988). OSR data files are reprocessed to create more concise job descriptions based on the TMs of the occupation. The CODAP MODULE programs are used to create a new occupational data base. Generally, four indices are used to characterize the association of jobs and task modules:

1. the sum, across people and tasks, of the percent time spent performing the tasks of a TM;
2. a running cumulation of the summed percent time spent index;
3. the average percent time spent per task in the TM; and
4. the average percent members performing across TM tasks.

Such job descriptions, using TM-level data to characterize the functions and responsibilities of job incumbents, provide a very concise picture of total job content. These summary descriptions are used as TDS data files [more complete descriptions can be generated showing all tasks by using ASCII CODAP Modules programs].

The identification of all the training courses and job assignment flows within an occupation is a more difficult problem. No existing single source provides all of the training data needed; no present sources provide suitable information on job flows, and no promising method of coordinating different sources is available. For TDS purposes, such information is synthesized from various sources to identify relevant courses, FTDs, PME programs, and occupation-unique training delivery systems. A Job and Training History survey is developed for use with a representative sample of experienced job incumbents (and a random sample of first-job personnel). Incumbents identify their present and previous jobs, and list dates of attendance for all training programs; they can also write in additional training programs. These data are used to estimate rates of attendance for the relevant courses for each job, attrition rates, and assignment flows (average length of assignment, PME course attendance points, etc.). Graphic flow patterns are developed, as well as narrative summaries. Such displays and data are validated with subject-matter experts (SMEs) in subsequent interviews or meetings (see example in Figure 2.6).

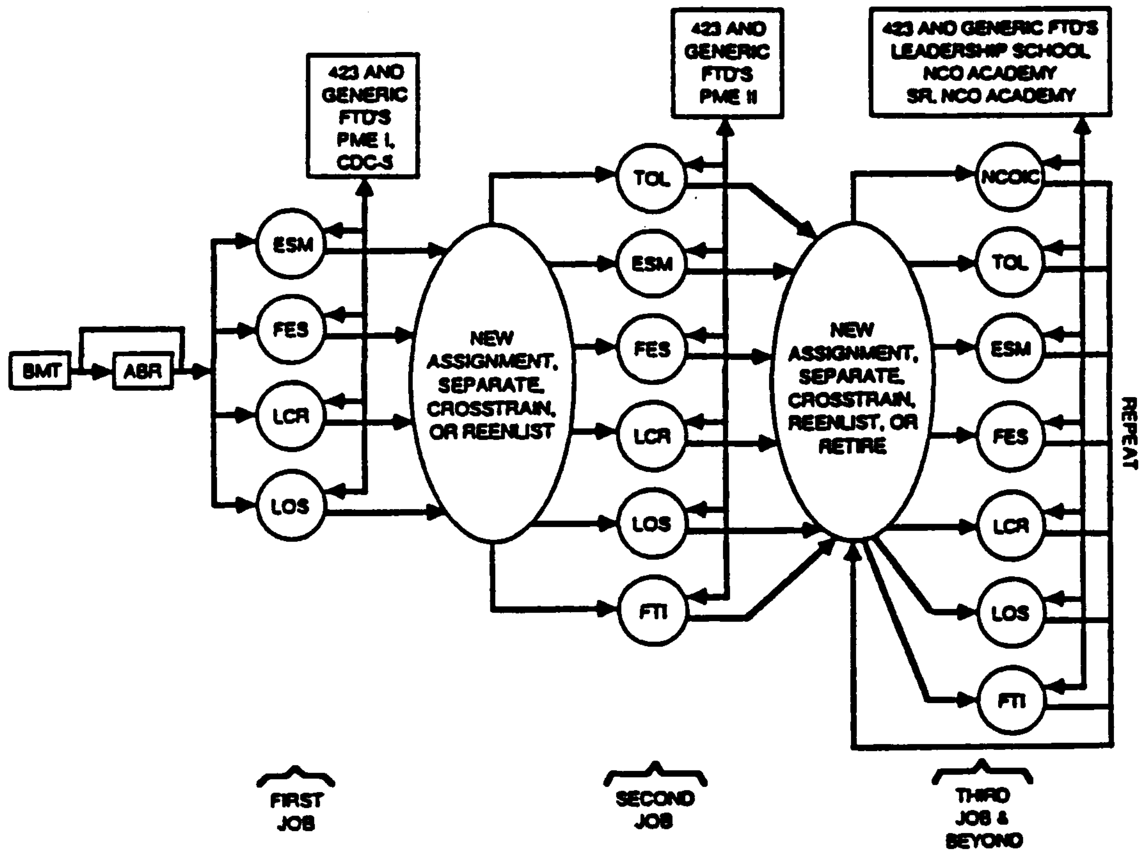


Figure 2.6. Example Utilization and Training Pattern Flow Diagram.

Graphic displays provide some sense of the flow of individuals through training programs and jobs but do not lend themselves to summarizing the various types of quantitative information involved, such as the number of individuals entering the field each year, or the various probabilities of reassignment among jobs, attending advanced technical training, or participating in PME courses (Mitchell, et al., 1988). In constructing the occupational model, an analyst must conceptualize the flow of personnel through these various training stages and sequences of jobs.

Once decisions are made as to which jobs and courses to include in the model of an occupation, and which categories of training (Job-driven, Time-driven, or Time and Job-driven) are most appropriate, then a quantitative flow model can be developed. Such data are best conceptualized as a series of data matrices which reflect the probabilities of personnel moving from training programs to initial jobs or from one job to another. To estimate every training-to-job and job-to-job probability becomes an extremely complex problem; new techniques had to be developed to simplify the problem and reduce the number of estimates which had to be made. This was done by collecting cases into a common reassignment pool - a "Collect."

Handling School- & Job-to-Collect Transitions (FRMJOB) - When individuals exit a training course or a job, they are collected in the simulation into one or more transition nodes, to simplify estimation of job assignment and advanced training probabilities. These transition nodes are called "Collects"; they are simply a device for making estimation of assignment probabilities feasible. Without such a mechanism, probability estimates would have to be made for every possible path between jobs, training states, and exits, which is overwhelmingly complex.

To specify these variable paths in the model, a data file is needed to define a set of tenure time ranges and identify the relevant collects. The FRMJOB file reflects which collect node individuals might go to (from each job and between-job training state) at each reassignment point (tenure range). The file has a row for each job and between-job training state and columns for the collects. In essence, this file is a mapping for the flow of people (entities) through the collect nodes.

Handling Collect-to-Job Probabilities (TOJOBS) - The third type of transition is from each collect to the next job or training program, or to exit from the field. By using this type of transition, it is possible to estimate the probabilities of such assignments by using OSR or JTHS data. The data are summarized for the specialty in the form of a data matrix having rows for each job and exit possibility (leave nodes). Leave nodes represent a summation of all ways of exiting the specialty. Columns of the TOJOBS matrix represent each transition node (collects). Each cell entry (data field) in the matrix contains the probability of moving from the collect to a job, between-job training state, or exit (Leave).

Even if we could accurately reconstruct the job and training history of all individuals in an AFS, this would not enable us to test alternative ways to organize the jobs and training programs or to evaluate predicted trends. To achieve the flexibility needed to assess the impact of proposed changes on a specialty, we need a dynamic simulation of the AFS which can be modified in order to test different job structures or different training configurations. Such a simulation creates job and training histories for a hypothetical AFS population for 10 to 20+ years in order to estimate the annual training requirements (including OJT) for the specialty. By modifying data files or input parameters (such an annual entries), we can see the impact of such changes on AFS training requirements and costs.

U&T Pattern Simulation (UTPSIM) Program. For any given set of input data (Current or some Alternative U&T Pattern), the TDS dynamic simulation program calculates how many individuals enter the system, flow through various training and job programs, and exit the specialty (Mitchell, et al., 1988; Yadrick, et al., 1988). The UTPSIM produces an Output Entity History file (OUTEHF) containing the job and formal training history of each simulated entity in the career field population and summary reports include monthly job and training flow statistics. Data files for a specialty are developed from a number of sources, to provide as accurate a picture as possible of the present jobs and training programs of the AFS (see Yadrick, et al., 1988). UTPSIM is then run to provide a basis for quantifying training requirements of the AFS and total annual training costs and training capacities of representative units are estimated with the Resource/Cost Subsystem (RCS) programs. Current U&T pattern results become the baseline for evaluating any proposed changes.

Training Proficiency (TRNPRF) Program - The TRNPRF computes the total amount of OJT needed in the specialty for all individuals to achieve required proficiency on the task modules (TMs) involved in their jobs. The TRNPRF uses the Entity History File (EHF) as its basic data file. It also employs the job identities (JOBIDS) file for the specialty and a run parameter (RUNPAR) file. The TRNPRF program is designed to estimate OJT requirements (in terms of needed training hours) for each entity in the EHF by accumulating, for each TM, the hours in each training setting (classroom, hand-on, self study, and OJT) received by the entity as he or she progresses through various training courses and jobs. Whenever an entity enters a job, after all within-job training has been accomplished (such as FTDs), the entity's proficiency level is computed for all TMs involved in the job. These computations are done using the running total training hours and the allocation curves. If the entity has less than full proficiency on an assigned TM, then OJT is required for that TM. The actual number of additional OJT hours required for full proficiency for each job-required TM can be computed using these allocation curves).

There are, however, two complications on this kind of computation in the TRNPRF. One is where the additional training hours required to achieve full proficiency exceed the maximum that can be attained by OJT. In such cases, the program accumulates the maximum effective hours (the program also keeps a record on the minimum proficiency level achieved on each TM under these circumstances). A second complication is where the number of TM training hours an entity has received exceeds the maximum effective hours (for that TM and setting); in this case, only the maximum effective hours are used to compute the entity's proficiency.

Such calculations are made for every entity in the Entity History File for all relevant TMs, depending on their jobs and the courses they have attended. These data are then accumulated into monthly training events. Such monthly statistics are compiled for all the monthly periods in the period of interest (a number of years) and an annual rate computed. The results of these computations are included the FUS Output file which is essentially a quantitative data base of all training requirements for the specialty.

Given successful runs of the UTPSIM and TRNPRF programs, their output files become the input files for a series of programs used in the RCS to compute training resource capacities and costs by site or program. The capacity programs will be used to evaluate whether the increased OJT can be handled by local OJT trainers or exceeds the capacity of some units.

The UTPSIM and TRNPRF programs provide an analyst with considerable flexibility for modeling various proposed changes to the jobs and the training programs of a specialty. The current U&T pattern serves as the baseline against which any new U&T pattern or change in parameters (such as input flow) can be assessed. The TRNPRF quantifies the training requirements for any U&T pattern at a very detailed level, and calculates the OJT requirements to support that pattern for every job and all relevant TMs. The TRNPRF Output File then becomes the primary input for the RCS programs in calculating training costs and capacities of representative units.

2.2.2.3 Resource/Cost Subsystem (RCS) Technologies

The RCS was developed in order to provide TDS three distinct, yet interrelated, analytic capabilities:

1. determination of the types and amounts of resources required to provide training on each TM in each training setting, and estimation of the amounts of those resources available for use in providing training at each site;

2. assessment of the capacities of various sites to accommodate different volumes of training on different combinations of TMs in different training states, where a training state consists of a set of specific amounts of training conducted on specific TMs in particular training settings; and

3. estimation of the variable costs that must be incurred in providing training on each TM in each training setting, and in providing particular volumes of training in specific training states.

To accomplish these objectives, the RCS was structured into three analytic components: a Resource Requirements Component (RRC), a Training Capacity Component (TCC), and a Cost Estimation Component (CEC). These components use input files from the TCS and FUS; compile resource requirements, availability and cost factor data; and interact with one another to generate resource and cost estimates (see Rueter, Feldsott, & Vaughan, 1989).

Resource Requirements Component. The RRC performs five data development functions. Specifically, it (a) determines the specific types of resources required to perform training on each TM in each training setting, (b) estimates the quantity of each identified type of resource required for training each TM in each setting, (c) produces compilations of those estimates classified on the basis of the ways in which the corresponding types of resources affect variable training costs and training capacities, (d) estimates the quantities of those resources available for the provision of training at various actual sites, and (e) delineates an appropriate set of representative sites for the particular specialty.

Inputs to this component include: TM definitions and amounts of time allocated for training the various TMs in different training settings (from the TCS), and preliminary lists of resources required for training each TM in each setting (collected via a Training Requirements Questionnaire administered to school and field trainers. Based on these inputs, an analyst identifies representative sites and develops the basic data for use in estimating training capacities and costs within the other two RCS components.

Representative sites (TTC courses, FTD courses, operational units) are identified to account for important locational variations in travel and temporary duty (TDY) costs, training loads, missions, resource availability, and other factors. The use of representative sites permits more economical collection of cost data and simplifies comparisons of resource availability and requirements. A key consideration in determining resource availability is the identification of the minimum resources required for operational duties at representative sites since operational requirements place real constraints on the training capability of units.

Training Capacity Component. The TCC evaluates the capacities of various representative sites to provide training in appropriate settings on different combinations of TMs and in training volumes that are compatible with the U&T patterns identified in the FUS. Inputs to this component consist of the following: TM combinations and training volumes for the various U&T patterns (from the FUS), predicted amounts of specific resources required for the provision of training on each TM in each training setting (in the form of regression equations from the RRC), and availabilities of those resources for providing training at each representative site. Resource availability data are collected in a Training Resources Availability survey of TTCs, FTDs, and representative field units. For dedicated training resources, data on the sharing of equipment and other resources must be collected since sharing has a potential impact on training capability, and may vary by site; only that amount of usage for the specialty of interest can be considered .

An analyst develops estimates of the capacity of each representative site to accommodate various combinations of TMs and training loads, and identifies any resource limitations that constrain representative sites from accommodating particular U&T patterns. When such constraints are encountered, they are displayed in the OJT Capacity Report for each site as "Trainees Unsupportable".

Inherent in this process is evaluation of the feasibility of resource substitution, the impact of training load on training quality, and the possible impact of training on mission performance (where a training deficit exists, then resources must be diverted from mission performance to provide training, or the unit runs the risk of error or accident which may result from the lack of complete training). Training capacity evaluations use statistical training resource requirement functions and mathematical programming formulations to assess various training options.

Cost Estimation Component (CEC). The CEC computes total annual variable costs for providing training of each TM in each training setting (assuming all required resources are available in sufficient quantities), and then compiles the cost estimates in a form compatible with the estimates developed for training capacity. Inputs to this process include: estimated training resource requirements (from the RRC), training states (i.e., amounts of time allocated to specific TMs in specific settings) and associated training volumes compatible with various U&T patterns (from the FUS), and unit resource cost factors from external Air Force data sources (TDY costs, instructor salary levels, costs of training equipment and supplies, etc.). By applying the unit cost factors to the estimated training resource requirements for the specified training states and training volumes, this component estimates the variable costs of conducting training in each training setting and for each specified training volume in the corresponding training state.

Once these very complex basic data sets have been developed, they must be synthesized and processed as formatted reports in such a way as to be useful for Air Force decision makers. This is done by operation of the RCS components and data files; the common starting point is the FUS Output File (from TRNPRF). Multiple processing is performed to generate training hours for trainees, trainers, and other resources, for both classroom and OJT requirements. It should be noted that the capacity and costing programs of the RCS operate in parallel, use some common data files as input, and use some unique files as well.

The major products of the RCS are data files and reports; these are organized by representative site, training setting, and job.

Such unit-level data are also aggregated to derive estimates for the total AFS, for MAJCOMs, and for individual bases in a summary section of the report. Separate reports of training capacity and costs are generated for the current U&T pattern and each alternative U&T pattern to create multiple RCS output files. [For more details on the RCS and its components, see Rueter et al., 1989.] RCS data files serve as the basis for comparing the impact of various suggested AFS changes, and for generating reports to respond to managers' inquiries, through the operations of the Integration and Optimization Subsystem.

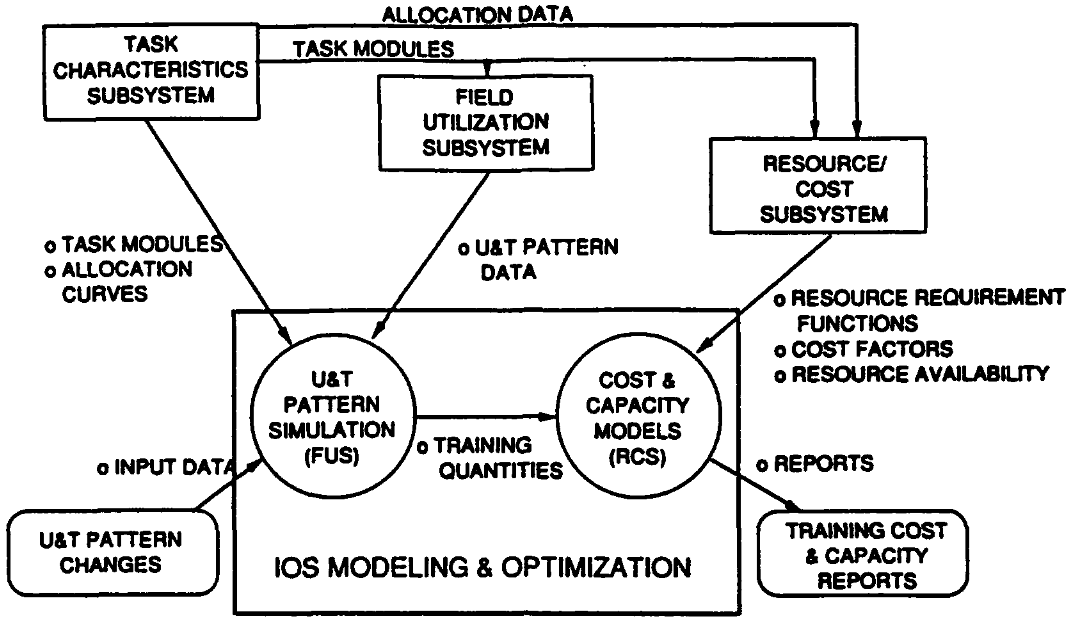
2.2.3 Integrated Technologies in the IOS

The IOS ties together the other three subsystems into one overall functional system (Figure 2.7; see also Figure 2.3, page 16). The IOS contains mechanisms which enable system modeling and optimization. The interconnections of the subsystems provide the capacity to optimize measures derived from one subsystem relative to constraints obtained from the others, and to simultaneously process data files derived from different subsystems. The IOS also provides the interface with users; that is, the subsystem receives all requests, calls appropriate data from the other subsystems or TDS files, and creates products to meet the users' needs. In all of its functions, the IOS governs the interaction among the TDS subsystems and various data sources, and the relationship of the system with various types of users. The IOS is structured to perform three types of functions:

2.2.3.1 Modeling Functions. The IOS processes information and data files from the TCS, FUS, and RCS to create various models of the AFS under consideration. The basic model for the AFS is the current U&T pattern; each alternative U&T pattern represents some change to the current U&T model. This approach provides maximum flexibility in the TDS, because an almost infinite number of possibilities can be considered.

The modeling functions of the IOS are not limited to examining the alternative U&T patterns formulated in the FUS (although AFS managers' preferences are collected only for these alternatives). Rather, IOS modeling provides the capability to change any input variable for any program, thus permitting examination of the impact of such change on the total system. For example, the simplest change would be to use the current FUS model and raise or lower the number of personnel entering the ABR course (modify the Trained Personnel Requirement or TPR). The system would then generate reports for comparison with the data from a baseline current U&T pattern run; differences in values (annual training costs, total AFS population in future years, etc.) would reflect the relative impact of the change. Another type of change would be to change the content of some course, such as the ABR, and then run the system to assess the changes in costs and total OJT requirements for the specialty.

Any major proposed change in a specialty should be dealt with as a formal alternative U&T pattern, so that possible consequences can be examined in some detail and data collected which describe Air Force managers' preferences among a set of alternatives. Some changes, such as a merger of several AFSs at the technician level (as proposed in RIVET



<u>Figure 2.7</u> The Integrated Training Decision System

WORKFORCE), may exceed present system capacities (unless a new OSR is accomplished using a redeveloped task list covering all specialties involved, or needed data are estimated in some other way).

Most of the possible changes which might be considered for an AFS can be modeled by changing input parameters, course content, job content, or career patterns within the TDS. Such changes are processed as modeling runs with specified values of selected variables. Analysis then focuses on how such changes impact on training capacity and total training costs. The training capacity reports generated in this process will also highlight any constraints on training capability in terms of training equipment, instructor availability, or other significant problems.

An example may serve to illustrate how potential changes can be evaluated. The problem might be a resource constraint in conducting OJT in some units, such as not enough hours when a piece of test equipment--a Weapons Release Control System (WRCS) Analyzer in the Radar and Inertial Navigation Systems Maintenance specialty (AFS 328X4)--is available for use in training. One approach to the problem would be to move training of that equipment from an OJT setting to a formal course (an FTD or the basic resident course at the TTC). The first possibility can be modeled in the TDS by adding enough hours to achieve the required proficiency (as indicated by the Allocation Curve for the WRCS TM) to the resident course. A second model would be to add hours for this training to the FTD course.

The results of these analyses are shown in Figure 2.8, along with data from the current U&T pattern as a baseline for comparison. It should be noted that the "Exceeded" under the Current U&T pattern (first column) indicates that some resource constraint exists (in this case, an equipment availability constraint). Note also that the proposed solution of adding the required WRCS Analyzer training to the FTD (third column, far right) did not solve the problem; OJT capacity is still exceeded. Moving the training to the resident (second column, middle) course does appear to solve the constraint problem, but at an additional ABR cost of about $20,000. There is, however, some offsetting reduction in OJT costs since WRCS Analyzer training was removed. In this particular example, the costs calculate out to be about the same but providing the training in the ABR does not exceed OJT capacity of units in the field. Obviously, this is a feasible and practical solution.

The point here is that once a problem and potential solutions have been identified, the IOS modeling capability can be used to translate the potential solutions into modifications of the specialty data base (the current U&T files) to create a new alternative U&T pattern. Each relevant data file is systematically examined and, where needed, modified to accurately portray the change. The TDS software is then employed to generate products for each potential solution and the resulting reports can be compared to the baseline data (current U&T products) by Air Force decision makers. Short summary comparisons can then be developed to highlight the changes (as in Figure 2.8).

	CURRENT PATTERN	AUGMENTED ABR COURSE	AUGMENTED FTD COURSE
ABR COURSE COSTS	$1,676,352	$1,696,406	$1,676,352
FTD COURSE COSTS	$ 45,647	$ 45,647	$ 53,495
TOTAL COURSES	$2,724,296	$2,744,350	$2,732,145
OJT COSTS	$5,096,500	$5,076,792	$5,095,981
OJT CAPACITY	EXCEEDED	NOT EXCEEDED	EXCEEDED

Figure 2.8. Comparison of AFS 328X4 U&T Patterns Involving Movement of WCRS Analyzer Training. (ABR = Airman Basic Resident; FTD = Field Training Detachment)

2.2.3.2 Optimization Functions. Given the almost limitless number of possible changes which might be studied, a TDS analyst or functional user might wish to take another approach to assessing specialty training changes. This approach could make use of the IOS optimization software. The analyst or user can specify an objective function or goal (such as minimization of OJT cost or total training costs, or maximization of the amount of available equipment, etc.), run the optimization program, and examine the effects on the specialty if the objective function is maximized or minimized. The analyst can ask "What if" questions; for example:

> What is the impact on total training costs if we minimize initial resident course instruction?
>
> What happens to specialty jobs (proficiency), if we maximize FTD training and minimize OJT?.
>
> What is the impact on proficiency acquisition and training costs, if we have a 10% cut in new recruits entering training?

Some potential optimization problems may become visible during modeling runs of the specialty as training constraints are identified, or possible new models may be suggested by initial optimization runs. Other possible optimizations will be suggested by general Air Force trends, such as budget cuts or changing operational priorities. In some cases, these could be complex problems with several constraints and multiple values to be optimized.

The approach taken in employing optimization algorithms to solve maximization or minimization problems in the TDS is to employ modular data bases and seek solutions at the lowest possible level. This isolates solutions to only the area of interest and has some efficiency in terms of saving computer time. Only the largest optimization problems, such as minimizing total specialty training costs, would require employment of the entire TDS data base. More limited problems can thus be dealt with by limited program runs.

The computer programs used to provide optimization runs were designed so that they can be interfaced with TDS data bases in the IOS. A detailed review of such software is beyond the scope of this overview report. For details of constraints, available routines, and procedures for using such software, see the TDS Procedural Guide (Vaughan, Mitchell, Marshall, Feldsott, & Rueter, 1988).

2.2.3.3 User Interface Functions. The IOS also serves as an interface with TDS users. It receives all requests, calls appropriate data from the other subsystems, and creates products to meet the users' needs. In its present configuration, the interface is handled through on-line computer requests (control cards, specification of variables, creation of required data files) and the resulting products (data files and reports).

2.3 Independent Yet Integrated Technologies

While each of the TDS subsystems and its required technological innovations were developed to be independent operations, they were developed sequentially so that new types of data or processes in one subsystem helped to pattern the technology possible in subsequent subsystems. For example, the Task Modules developed in the R&D of the TCS served as the basis for development of U&T patterns in the FUS and resource requirements and availability surveying in the RCS. However, the specific techniques used to cluster tasks into TMs (i.e., co-performance clustering using CODAP) are not critical to the operation of the TCS or the other subsystems; any clustering or presorting process could be used as long as the resulting TMs had the desired characteristics (shared skill and knowledge requirements; some efficiency through common training).

In addition, the co-performance task clustering technology may have uses and applications which are not necessarily related to the TDS. Such task clustering might have a number of potential uses and included task clustering in the major revision CODAP project which was already underway. This new task clustering technology is presently being used operationally by the USAFOMC and other research organizations as an aide in identifying and interpreting job types within occupations (Phalen, et al., 1987, 1988).

Thus, we can say that the innovative co-performance clustering technology which was developed in the TCS R&D is an <u>independent</u> technology - one which is useful in the TDS but not critical to the success of the system (i.e., other task groupings could be used) <u>and</u> is a technology which has potential utility for other applications not involved with the TDS. The same can be said of other technologies developed for use in the TDS subsystems including U&T pattern modeling, the U&TP simulation, the training proficiency requirements analysis (allocation curves), resource requirements and availability accounting, technology for assessing unit OJT capabilities at representative sites, and estimation of composite training costs and capabilities for a specialty. Each of these technologies is a highly useful part of its subsystem and of the TDS as a whole, but are, for the most part, independent technologies which have potential in a variety of non-TDS applications.

To give a second example, the U&T Pattern modeling with its more dynamic portrayal of the jobs and training programs over the span of a 10 to 20+ year period is itself a technological innovation. It goes beyond the static picture of a specialty presently used in the USAF occupational analysis program (Mitchell, et al., 1988). Thus, it has potential for application in normal occupational analysis operations quite independent of its present use in the TDS. Further, it is not critical to the operation of the FUS per se; that is, other ways of modeling the specialty could be used as long as they were useful in the conceptualization of the occupation and aided in the estimation of training-to-job, job-to-training, and job-to-job probabilities. Thus, while the present U&T modeling technology is an integral part of the TDS, it is also an independent technology with other possible applications.

Most of the "pieces" of technology developed in the TDS R&D were designed as independent technologies. This was done so that as other new technologies were developed, they could be implemented with minimum difficulty. This modular approach was intentional; it makes the TDS a very flexible system which can remain useful as techniques and major training decision making processes change (see Mitchell, et al., 1987).

We expect that such innovative methodological and technological changes will also make obvious a need for a technologically-advanced data collection, generation, analysis, and evaluation capability. Such changes, which might be linked to broader innovations in computer (PC) administration of surveys, automated flow of survey data from bases to AFMPC or the USAFOMC, or other data integration mechanisms, may themselves suggest alternative methods and techniques for improving the TDS.

To make good decisions about the training needed for an Air Force specialty or system, decision makers must be able to visualize and understand the jobs and training programs of the specialty or weapon system under consideration and its technical training and Professional Military Education implications. To assist and aid in such decision making, the TDS must be flexible enough to incorporate new and different sources of information or alternative methodologies for accomplishing its functions. If, for example, new cost accounting procedures for determining the costs involved in FTD operations were developed which proved to be more realistic than current TDS estimates, then data from the new FTD costing method should be incorporated into the TDS.

In this way, the flexible TDS design can be continually refined and updated to take advantage of new technologies as they are developed. Only in this way can the TDS remain at the "cutting edge" of the various scientific areas involved and maintain its utility to the Air Force.

3.0 SCIENTIFIC CONTRIBUTIONS OF THE TDS RESEARCH

A number of the technologies developed in the course of the exploratory Training Decisions System research and development project utilized state-of-the-art techniques and operational concepts from a number of technical areas. This chapter will review several of these technologies in light of the present state-of-the-art with the view of explicating what implications the TDS R&D results have for the future of the relevant technical area (academic disciplines).

3.1 Top-Down Structured Systems Design & Operations Research

The initial development of the TDS was undertaken within the conceptual framework outlined in the statement of work (SOW). The SOW specified an overall system architecture (noted in Figure 2.3), but provided few details of subsystem operations or structure. Subsequent to the initial TDS Progress Review (in early 1984), one of the senior AFHRL managers pointed out the need for a detailed preliminary systems design, and suggested that sophisticated methodologies were available in the recent Operations Research/Systems Analysis literature which might be useful.

3.1.1 Top-Down Structured Analysis System

The TDS Preliminary Design was developed using a top-down structured systems design approach (Vaughan, et al., 1984). The preliminary design identified the purpose and potential uses of the TDS, specified the subsystems and their relationship with data sources, and identified components within each subsystem to accomplish specific required functions (ibid.). This preliminary design was conceptualized as a flow of inputs from a number of sources, processing in the TDS subsystems, and outputs consisting of user reports and data files. It was based, in part, on successful earlier OJT cost analysis and capacity modeling R&D (Eisele, Bell, & Laidlaw, 1978; Rueter, Bell, & Malloy, 1980), as well as on SOW requirements and rational design considerations.

In 1985, a reanalysis of the system requirements was undertaken to expedite the development of a TDS Demonstrator. This microcomputer-based demonstrator was requested by AFHRL to help communicate possible TDS capabilities and functions to potential users of the system. In the development of the demonstrator, it was necessary to specify the overall systems design and subsystem specifications at a greater level of detail than previously had been required.

3.1.2 Use of STRADIS in TDS Design

After review of a number of available software development systems, the Structured Analysis Design of Information Systems (STRADIS) was selected to assist in the overall system software design. STRADIS is a top-down structured analysis system which guides design efforts based on overall program objectives and parameters. It involves multiple levels of design, beginning with overall system goals, to insure that adequate details are available for software designers and data developers. STRADIS is a program developed within the McDonnell Douglas Corporation (MDC) and is used to assist in systems design throughout

MDC. While it includes proprietary software, as an MDC product it could be used for the TDS project without fee (i.e., at no additional cost to the government).

A three-level design was developed which provided for an overall systems design, specification of each TDS subsystem, and details of the required integration of subsystem data files and outputs into reports for users of the system through the Integration/Optimization subsystem executive component (see Mitchell, et al., 1985 [revision A, September 1987]: Figures 4.1 and 4.2, and Appendix B). This more comprehensive systems design and specifications were used in the later development of the proof-of-concept system. While some details of the final system varied from the STRADIS design, this was generally the result of problems in data collection or because of innovative new technologies developed later during the R&D effort; the overall design proved to be sufficiently detailed for use in the development of the system and its supporting software.

Thus, state-of-the-art, top-down structured analysis methods were used in developing the final TDS design. They proved extremely useful in guiding the work of creating the subsystems and their data collection and files. It was also used to guide the development of software needed to support an operational TDS. Some of the results of the final TDS design and issues which arose in the TDS R&D have implications for the general areas of Operations Research and Systems Analysis.

3.1.3 Implications of TDS for Operations Research & Systems Analysis

The final TDS was successful in terms of integrating very divergent data from a myriad of sources and in processing such data in such a way as to achieve a here-to-fore impossible result--a realistic estimate of the major costs of Air Force on-the-job training programs within a specialty. By proper formatting of data, it was possible to integrate occupational analysis results (task and job data and patterns) with personnel and training data (personnel flow rates; training flows and attrition rates) as well as cost data (manpower costs, travel and per diem rates, resource costs and availabilities) to achieve the desired result. This type of use of totally independent data sources is not new in the area of operations research, but an application in the area of quantifying specialty training requirements and estimating the costs of OJT programs is clearly innovative.

The implication for Operations Research and Systems Analysis is that it is quite possible to merge data from several independent technologies to create new and useful applications. The need for this kind of joint technological development among diverse academic areas will probably increase in the future as the success of this type of innovative application becomes known to Human Resources and MPT managers and planners.

A second implication of the TDS R&D project comes from the creation of a TDS demonstrator to simulate operation of the system. This was a very useful adjunct for the TDS R&D effort in that it permitted potential users to better visualize the operation of a completed system. It was more specifically useful in letting users review report formats and the amounts of information being presented. As a result of feedback from potential users, data report formats were redesigned and several new types of displays were created (for the TDS; they have not yet been modified in the demonstrator). Thus, in any R&D effort, it may be useful to create this type of demonstrator, to properly communicate the appearance and functions of the system being developed.

3.2 TDS Cost Estimation and Cost Accounting Models

The main conceptual issue that had to be resolved in developing cost estimation procedures for use in the Resource/Cost Subsystem (RCS) of the Training Decisions System (TDS) was the proper allocation of the costs of shared resources among the different applications in which they are utilized. Resources that are used in the provision of Air Force training are shared among different applications in four distinct ways. Specifically, individual resources may be shared:

(1) between training programs and operational duties,
(2) among training programs in different Air Force specialties,
(3) among training on different task modules (TMs) in individual AFSs, and
(4) between group instruction and training of individual personnel.

In developing the procedures used in the RCS to allocate appropriate portions of the costs of such resources to specific training applications (i.e., to the provision of training on specific TMs within specific AFSs in specific training settings), the basic principles and techniques of activity-based costing have been applied.

3.2.1 Activity-Based Costing

Activity-based costing is an emerging approach to cost accounting that is being adopted by increasing numbers of manufacturing companies. The fundamental principles upon which it is based are that "...activities consume resources and products consume activities" (Turney, 1989, p. 25). Turney further explains:

> Activities are procedures or processes that cause work ...The performance of these activities triggers the consumption of resources that are recorded as costs in the accounts. The activities are performed in response to the need to design, produce, and distribute products (Turney, 1989: 25).

Therefore, in allocating the costs of shared resources to specific products:

> Activity-based costing traces costs to products according to the activities performed on them (Turney, 1989: 23).

To apply these principles to estimation of the costs of training programs, it is necessary merely to interpret the training programs as products, and to interpret the use of resources in the provision of group instruction or individual personnel training on specific TMs in specific training settings as activities.

Activity-based costing explicitly recognizes that the costs associated with different activities can originate from distinctly different basic operations. Accordingly, in activity-based costing, the costs associated with different activities are allocated to individual products based on the distinct operations that drive the costs. For example, in a manufacturing situation, the costs involved in setting up a production run are first traced to the specific product that created the demand for the setup activities, and then are apportioned over the units of that product manufactured in that production run. In this manner, low-volume products properly incur relatively high costs per unit for setup activities, whereas high-volume products incur relatively low unit setup costs (Turney, 1989: 25). Similarly, in the RCS, the costs associated with group instruction are first related to the size of the group receiving the instruction, and are then spread over the term of the training received by the group, thereby deriving an appropriate estimate of cost per student week for the training program.

3.2.2 Comparison to Traditional Costing

In contrast, in the same situations, traditional costing would allocate setup costs among products, and group instruction costs among training programs, on the basis of measures related to total volumes of production and training,such as total direct labor hours and total direct trainee hours. Traditional costing would, therefore, incorrectly allocate an equal amount of setup cost to each direct labor hour and an equal amount of group instruction cost to each direct trainee hour, regardless of the length of the production run in which the product was manufactured and the size of the group to which the training program was delivered. As a result, traditional costing would generally provide distorted estimates of the costs of individual products and individual training programs. Distortions would occur because volume-related cost drivers fail to trace the costs of volume-unrelated activities correctly.

Distorted cost estimates inherently involve cross-subsidies, wherein one product or training program absorbs costs that properly should be assigned to another product or training program (Turney, 1989: 25). More importantly, managerial misinterpretations of distorted cost estimates as accurate measures of the incremental costs of individual products or training programs can cause incorrect resource allocation decisions. At the extreme, as Kaplan stresses:

> Seriously distorted product costs can lead managers to choose a losing competitive strategy by deemphasizing and overpricing products that are highly profitable and by expanding commitments to complex, unprofitable lines (Kaplan, 1988: 64).

Conversely, as Turney states:

> ...activity-based costing eliminates cross-subsidy by using volume-unrelated cost drivers to trace the cost of volume-unrelated activities to the product (Turney, 1989: 25-26).

For example, within the RCS, cost estimates for resources used in group instruction are, in effect, based on the number of groups entering into the training program, rather than just the number of personnel involved in the program.

3.2.3 Development of an Activity-Based Costing System

A good activity-based costing system should account for pertinent expenses incurred throughout the entire organization. As Kaplan explains:

> All company resources support production and sales. Even corporate expenses should be allocated to product costs, especially if they vary across product lines (Kaplan, 1988: 65).

Thus, an effectual costing system must determine how indirect costs vary, both with regard to volume and with regard to the activities associated with the multiple applications of the shared resources. Often, extensive allocations of the costs incurred by support departments will be necessary to develop estimates of the costs of the activities performed by the departments (Kaplan, 1988: 64).

In such situations, the tracing of costs from resources to activities and then from activities to applications cannot be performed with great precision. Rather, as Cooper and Kaplan emphasize:

> ...it is better to be basically correct with activity- based costing, say, within 5% or 10% of the actual demands a product makes on organizational resources, than to be precisely wrong (perhaps by as much as 200%) using outdated allocation techniques (Cooper and Kaplan, 1988: 100).

3.2.3.1 Subjectivity - The cost estimates developed by activity-based costing systems will also be more subjective than those derived with traditional costing methods (Kaplan, 1988: 64). Cooper and Kaplan explain:

> The process of designing and implementing an activity- based cost system for support departments usually begins with interviews of the department heads. The interviews yield insights into departmental operations and into the factors that trigger departmental activities. Subsequent analysis traces these activities to specific products (Cooper and Kaplan, 1988: 99).

In accord with these precepts, the basic approach that has been used in allocating the costs of shared resources in the initial implementation of the RCS has involved, first, interviewing subject-matter experts (SMEs) at Air Training Command (ATC) headquarters, the headquarters of the operational major commands, and the Air Staff to determine how Air Force training is organized, and how resources are used in performing that training. Then, questionnaires have been distributed to a larger number of SMEs to obtain their estimates of the amounts, or proportions, of time that trainers, trainees, or specific types of equipment typically are or should be involved in group instruction or individual personnel training on particular TMs in specific training settings. Estimates of the numbers of trainees who currently do or should use the various shared resources in each situation have also been obtained from these SMEs. The judgments furnished by the SMEs have then been used as the bases for allocating appropriate portions of the corresponding shared resources to individual TMs.

3.2.3.2 Simplicity - Although a good activity-based costing system must be comprehensive, its design should not be unnecessarily complex. The cost of developing, operating, and maintaining a system can be decreased by simplifying its design. Therefore, a well-designed system should provide no more detail than that required for the situation in which it is intended to operate (Turney, 1989: 30-31).

3.2.3.3 Adaptability - Unless an organization makes major changes in its structure, technology, or mode of operation, it usually is unnecessary to conduct additional interviews, surveys, or data analyses more often than once per year (Kaplan, 1988: 65). Rather, by combining existing data with reasoned judgments about certain salient factors, an organization can normally develop serviceable estimates of the costs of new or modified products or programs by assessing their demands on associated activities and resources. Indeed, this capability is the primary reason for adopting activity-based costing as the basis for the cost analysis procedures implemented in the RCS.

3.2.4 Implications of TDS for Cost Accounting & Econometrics

The TDS uses current state-of-the-art cost accounting and econometric modeling for estimating specialty training costs; the application of such techniques for calculating on-the-job training costs and capacities is an innovative new use for these technical areas. This particular approach has yielded reasonable estimates of OJT costs which have never previously been possible. For the first time, such "hidden" training costs can be made visible to functional managers, training staff personnel, and commanders.

One of the implications of the successful TDS R&D project for the cost accounting area is in the TDS RCS costing of major restructuring alternatives. This involves the capability for predicting the costs of major changes in jobs and training programs. Traditional cost accounting has generally been involved in assessing present costs or, at the most, only estimating costs for small, incremental changes.

The success of the TDS R&D project indicates that estimating the costs for major future possibilities or configurations can be accomplished with this approach. Thus, activity-based cost accounting can be used in a planning mode to estimate costs for alternative configurations, which considerably extends the traditional role of cost accounting through integration with econometric modeling and MPT planning.

3.3 TDS Allocation Curves and Learning Curves

In general, learning curves are mathematical functions which translate the amount of training into performance level. "Amount of training" may be operationalized as number of training trials, training time, or in other ways. Performance level has been operationalized in various ways, including time-to-perform and quality of performance, measured or assessed in many different ways.

3.3.1 TDS Allocation Curves as Learning Curves

As discussed earlier, in TDS allocation curves relate training time to proficiency level. Thus, TDS allocation curves may be viewed as learning curves, and the scientific findings concerning learning curves are directly relevant. Research on learning curves has been done in at least three academic disciplines--experimental psychology, education, and industrial engineering. Learning curve research in industrial engineering has been concerned with efficiency improvements in a manufacturing process related to amount of experience with the process. These research results are not particularly relevant to the TDS and are not reviewed here. What is relevant is that by using allocation curves to translate training hours in various settings into amounts of relative proficiency, we have, for the first time, been able to develop a system for dealing with all possible combinations of training. This is remarkably innovative, and permits the TDS a degree of flexibility in considering alternative training configurations which has not been possible in the past (nor in most decision support systems). This is made possible by dealing with allocation curves as learning curves.

A brief review is presented below of learning curve findings in experimental psychology as related to the TDS.

3.3.2 Learning Curves in Experimental Psychology

Learning has been one of the major topics of experimental psychology. A massive literature on learning curves exists in experimental psychology. Typical studies involve learning of extremely small and structured tasks, such as in paired associate learning. Learning curves typically relate numbers of learning trials to response speed. Anderson (1980) sums up the findings of this whole area of learning curve research:

> "In fact, virtually every study of skill acquisition has found a straight-line function on a log-log plot" [227].

This relationship reflects a power law:

$$\text{proficiency} = \underline{a} * (\text{training time})^{\underline{b}},$$

where $\underline{a}$ and $\underline{b}$ are model parameters.

This function has two key features: it is negatively accelerating and zero training time produces zero proficiency. TDS allocation curves, however, have a somewhat different mathematical function:

$$\text{proficiency} = \underline{a} * (\text{training time}) + \underline{b} * (\text{training time})^{2}.$$

However, this function produces zero proficiency for zero training time. Also, if $\underline{b}$ is negative, this function is negatively accelerated. As a matter of empirical fact, $\underline{b}$ is negative or zero for all existing TDS allocation curves. Thus, TDS allocation curves are consistent with the experimental psychology learning curve findings.

The second order polynomial functional form used for allocation curves permitted a direct test of the negative acceleration feature, which the power law function does not. Thus, the polynomial function offers advantages. However, it would be worthwhile in future TDS research to examine the power law function for allocation curves.

3.3.3 Application in the TDS

The TDS allocation curves are used to translate hours of training time for each TM among various training settings. This provides a flexibility to the system which enhances its capability for use in evaluating possible alternative configurations of training. Given the capability to equate training hours and gain in proficiency among various training settings, it is possible to consider a wide range of possible configurations of training (and, indeed, to optimize efficiency in terms of minimizing training costs). This use of learning curve technology appears to use state-of-the-art technology in a unique new application; for planning future changes and evaluating such possible changes in terms of training cost consequences.

3.3.4 Implications of TDS for Experimental and Educational Psychology

The use of allocation curves in the TDS is a very practical and effective application of experimental results to help solve real world problems. The implication of the success of the TDS R&D is that there are great benefits to be realized from developing and validating the use of experimental results to help solve real world problems. TDS use of allocation curves also demonstrates the value of merging the technologies of diverse disciplines; in this case, the combination of using Experimental and Educational Psychology research (learning curves) with innovative cost accounting predictions to assess possible future changes in job and training programs.

The successful use of allocation curves as multiple functions relating training time in various settings to the degree of relative proficiency achieved demonstrates that by developing a very flexible system, researchers or analysts can provide decision makers with much more useful tools to assist in their decision making than was previously thought possible. In the past, decisions have been made subjectively for lack of such tools, and the impacts of such decisions could not be evaluated until their real effects became obvious. The TDS project has demonstrated that such decisions can indeed be modeled and that even complex issues can be evaluated through quantitative modeling techniques.

3.4 TDS & Industrial/Organizational Psychology

There are a number of areas where the TDS R&D effort made use of state-of-the-art research results, procedures, and operational concepts from the area of I/O psychology. These areas include task-based job (occupational) analysis, data collection, statistical analysis techniques, and modeling.

3.4.1 Task Clustering

One of the major problems in the design of TDS was how to best utilize the massive amounts of task data generated for each AFS in the Air Force occupational analysis program. The technological challenge was to find a systematic way to systematically reduce the data to a reasonable number of categories which could used as a basis for describing jobs or training programs and to be the unit of analysis for costing and capacity estimation. The objective was to create groups of tasks or Task Modules (TMs) which share common skills and knowledges and thus represent some efficiency in being trained together (Perrin, et al., 1988).

3.4.1.1 Statistical Clustering - An extensive review of the literature concerning statistical clustering technologies was conducted to identify candidate techniques for task clustering (Vaughan, Yadrick, Dunteman, and Clark, 1984:8). While there are a variety of statistical techniques available, few if any, had previously been applied to the clustering of tasks, since task-based job analysis is largely a military related activity (Mitchell, 1988). Other job analysis approaches have tended to use factor analysis and related technologies since their objectives focus on the identification of more generic dimensions of work (Primoff and Fine, 1988). Among the clustering methods examined were: the Q-Sort (Stephenson, 1969) which uses subject-matter experts judgements; medium technological methods (Mulligan, 1981a & b; Morey, Blashfield, & Skinner, 1983; Mojena, 1977; Kuiper & Fisher, 1975); and statistical algorithms for hierarchical clustering (Edelbrock, 1979; Ward, 1963; Ward & Hook, 1963). Such studies often present statistical indices of clustering accuracy, including the Rand statistic (Rand, 1971) or Kappa (Edelbrock, 1979).

As a result of the literature review, two basic clustering techniques were selected for further evaluation (Vaughan, Yadrick, Dunteman, & Clark, 1984). These were the Ward & Hook algorithm (Ward, 1963; Ward & Hook, 1963) and the average linkage algorithm, both agglomerative hierarchical techniques. These start with n separate single-member groups, then form n-1 groups, etc., and so on, until all cases are included in a single group. An analyst must determine the intermediate point at which optimal clusters exist. The Ward & Hook algorithm attempts to minimize the variance within clusters, while the average linkage algorithm attempts to minimize the difference between the group mean and any group member.

Another issue concerned the selection of the distance measure to be used in clustering tasks; a number of such measures were considered including Euclidean distance, city-block distance, and other Mahalobian distance measures, as well as task performance overlap (task co- performance).

After extensive field evaluations comparing candidate task clustering methodologies, a procedure for the development of TMs was developed which makes use of both statistical clustering and SME judgements (Perrin, et al., 1986). This procedure was validated with two additional specialties and was found to be realistic and cost effective (Perrin, Mitchell, & Knight, 1986). The final recommended procedure is one which combines the power of statistical clustering with the specialty judgements of SMEs, thus capturing the advantages of both methods (Perrin, et al., 1988; Vaughan, Mitchell, et al., 1989).

3.4.1.2 Task Clustering and CODAP - In the process of developing task clustering procedures, the Comprehensive Occupational Data Analysis Programs (CODAP) were used; the task data to be used for clustering resides in CODAP files and the Ward-Hook Algorithm is used in this system. By transposing the typical CODAP case file, a clustering of tasks across cases became possible using existing hierarchical clustering programs (Perrin, et al., 1986). Interpretation aids, in the form of reports of background data were not available; only a K-Path listing of task statements could be generated for this purpose.

Several possible improvements to facilitate task clustering in CODAP were evident and were discussed with the AFHRL task scientist responsible for CODAP since a major revision of the system was underway. As a result of these discussions, several major innovations were introduced into CODAP including a transpose program and a new cummulative time-spent function for MODULE reports. These innovations were extremely useful in completing the task clustering activities required for the four AFSs studied in the TDS R&D project.

3.4.1.3 Subsequent ASCII CODAP Developments - TDS task clustering activities were briefed in a number of forums to potential TDS users, occupational analysts, I/O psychologists, and others (Perrin, Vaughan, et al., 1985; Yadrick, Vaughan, et al., 1985; Vaughan, Yadrick, et al. 1985; Mitchell and Phalen, 1985; Phalen and Mitchell, 1987). These briefings and TDS reports clearly demonstrated some of the potential value to job analysts and others of clustering tasks into task modules. As a result, the redevelopment of CODAP (into ASCII CODAP) project included provision for further refinement of this new technique and creation of products to aid analysts interpret hierarchical task clustering diagrams.

The revised ASCII CODAP system, which is now operational at AFHRL and the USAF Occupational Measurement Center, include several new task clustering capabilities. The system has added various other ways of computing co-performance (raw ratings, time spent, symmetrical versus asymmetrical, geometric mean, etc). In fact, any sort of other basis for clustering (such as with task difficulty, etc.) are now feasible in ASCII CODAP (Hand, Haynes, and Weissmuller, 1989). Such capabilities go far beyond what was originally needed for TDS but provide a more general utility to the system.

New interpretive programs have also been developed. MODTYP is a new ASCII CODAP program to assist in the selection of appropriate task clusters (Hand, et al., 1989:26). TASSET is a program used for looking at the most representative tasks (most discriminating tasks of a task cluster). CORCAS is used for identifying those cases most representative of a task cluster (or most important); it automatically orders cases in terms of their discrimination value for representativeness to task clusters (Ibid.).

These programs are now fully developed and are undergoing operational testing (Phalen, et al., 1989). In addition new extensions of this task clustering technology are under development including: JOBMOD for relating job types to task modules (matrix of relationships) and CLUSMAP for mapping the two-way distribution of cases and task modules in terms of their joint distribution of time spent ratings (Ibid.).

3.4.1.4 Implications for Training Decisions Technology - The very rapid development of task clustering technology since the TDS R&D use in developing TMs for the initial four

TDS specialties, suggests that a variety of new methods are now available for use in any further TDS R&D efforts. These new methods and techniques should be operationally tested in the new TDS R&D project through their application with additional AFSs. If validated, these new techniques could save considerable time and effort for TDS task module development efforts. In addition, new display techniques, such as CLUSMAP noted above, may prove beneficial in the validation and review of OSR job types for use in the TDS and other task-based R&D efforts.

It should be noted that the task clustering developments in ASCII CODAP came about in part because of the needs of the TDS R&D. Such ASCII CODAP developments in task clustering, however, have progressed far beyond what was originally suggested; indeed, they have resulted in a more general task clustering technology which can be applied in the on-going occupational analysis program. As Tartell has recently noted:

> ... There are too many tasks in occupations and too few personnel available for training design. As a partial solution to this dilemma, the task clustering concept allows the collapsing of long lists of tasks into a much smaller number of clusters. These task clusters have the advantage of being based in occupational data which means that the tasks have some basis for being grouped together. The logical extension of task clusters is cluster analysis for underlying constructs. This approach lessens the workload without diminishing the utility of the information. (Tartell, 1988:307).

Thus, this TDS-inspired interest and development have resulted in a series of practical applications for the task cluster or task module approach to assessing occupational jobs and training programs. This technological innovation has found rapid acceptance in the OA arena and has great potential utility both for clarifying the identification of job types and in improving the efficiency of training development (Ibid.).

3.4.2 Utilization and Training Pattern Modeling

A second area where the TDS R&D made use of state-of-the-art technology was in the area of job typing and the description of utilization and training (U&T) patterns based on occupational analysis data. As noted in Chapter 2, the TDS is designed to model an AFS in such a way as to make calculation of the annual flow of people through jobs and training programs possible and, in turn the quantification of training requirements, including OJT programs. This is done in order to predict the costs of all types of training as well as assess the capacity of representative field units to support OJT (Vaughan, et al., 1989).

3.4.2.1 Assignment Probabilities - The Field Utilization Subsystem (FUS) was designed to make use of the most current developments in occupational analysis (OA) technology (Yadrick, et al., 1988). However, the present OA system utilized by the Air Force collects cross-sectional data, thus developing a picture of the jobs and training of an AFS at a given point in time (Ruck, 1982; Mitchell, et al., 1987; 1988). The technological challenge for the TDS R&D project was to find a way to utilize such cross-sectional data to estimate job flows and assignment probabilities in a dynamic simulation or to collect new data which would permit creation of a personnel and training flow model.

This was done successfully in the TDS R&D project, by reanalyzing OA data by average assignment period (TAFMS year groups) and combining the static OA data with statistics from a Job and Training History survey as well as flow statistics from ATC and the Uniform Airman Record (UAR) files. By using a modeling mechanism to pool all reassignees at a particular TAFMS point into a single group (a "collect" - see Chapter 2), we were able to use percent of total group membership as an assignment probability, thus solving one of the most difficult estimation problems in the project (Yadrick, et al., 1988; Vaughan, et al., 1989). This made possible the development of a dynamic simulation of AFSs which can estimate annual job assignment and training program attendance probabilities with a reasonable degree of accuracy (Yadrick, et al., 1989; Mitchell, et al., 1987). Given this technological breakthrough, the remaining problems in modeling of AF specialties were solvable and the TDS became a reality (Vaughan, et al., 1989). Such modeling provides the flexibility needed to deal not only with the present AFS status (Current U&T Pattern) but any reasonable other AFS structure which might be proposed (Alternate U&T).

3.4.2.2 Implications for Occupational Analysis - This new AFS modeling capability exceeds the present technological development in any task-based job or occupational analysis system (see Gael 1988 for a comprehensive review of this technical area). The ability to construct a model of a specialty which provides a more dynamic picture of the jobs and training requirements of the occupation thus represents a major new innovation for the occupational analysis technological area.

Although the TDS was developed primarily for the use of the Air Force in supporting training decisions, the technological breakthrough in TDS modeling of AFS U&T patterns is of broader scope than just training decisions. This technology could be used to enhance the reporting of AFS data in the normal OA process for other uses, particularly for communicating to others the complex jobs and training programs which presently exist and for examination of current AFS structures and re- specification of responsibilities (AFR 39-1).

Future TDS R&D should focus on identifying other potential uses for this kind of occupational modeling, particularly in the areas of multi-specialty studies and the new weapon systems acquisition process (see the TDS Transition Plan; Vaughan, et al., 1985). The system might also have application in inter-service studies or for civilian use.

3.4.3 Data Collection Methods

A third area where TDS made use of state-of-the-art technologies was in development and use of data collection instruments. Again, the types of surveys done in the TDS R&D were based on current Air Force OA technology, but went beyond the present state of this technology by collecting information from more carefully selected target samples and by collecting tailored sets of information from targeted groups of SMEs.

3.4.3.1 TDS Surveys - Allocation surveys, for example, which would have been overwhelmingly complex if one survey had been administered to all SMEs, were divided into shorter, more realistic groupings of TMs; these were administered to just those SMEs known to be experienced with the tasks involved (as identified by OA job group membership from the last OSR). This approach proved quite successful (Perrin, et al., 1988). Likewise, job and training history surveys were targeted to individuals from the last OSR assigned to identified job groups (plus a random sample of recruits with six months to two years in their initial assignments). This provided a more realistic sample for the purpose of computing job membership and job-based school attendance than would have been possible with even a much large random sample (Yadrick, et al., 1988).

Data collection for the Resource/Cost Subsystem surveys used much smaller samples, since only one or two individuals would have the information as to resource requirements for teaching a resident course or a specific FTD. These data collection efforts also required more in terms of the amount of detail needed on particular types of training resources, how much they are used at present, and their availability for use in other courses or AFSs (the allocation of shared equipment or resources). In the case of the RCS surveys, personalized administration proved a necessity in order to standardize instructions and answers to respondents questions. Where personal administration was not possible (as with some remote or overseas FTD courses), very extensive telephone interaction was made to insure that the SMEs understood the task and had the same opportunity to have their questions answered. There were some inadequacies of the information gathered through this process; future work should focus on methods to insure more complete data for RCS use.

3.4.3.2 Data Collection Methodological Research - Where there was any question as to the suitability of a data collection method, the TDS data collection effort could itself be used as a laboratory to assess alternative methodologies. For example, while it has long been maintained that collecting multiple ratings of the same items (tasks or task modules) on the same rating form creates an artificial inflation of some ratings, there was very little formal literature to support this assertion. The allocation rating project provided an excellent opportunity to test this assertion, and to determine which data collection format was more realistic for TDS use.

An experimental design was developed which used different survey formats (multiple ratings on one form versus ratings on separate forms in the same booklet) and were administered to randomly assigned SMEs in the same AFS. Analysis of results indicated that there was indeed a statistically significant artifactual inflation of correlations (.10 or greater) between scales when the data were collected on a single rating form (Perrin, et al., 1987). If this result can be confirmed by other OA researchers in independent studies, it has very substantial implications for future OA data collection efforts, as well as other AFHRL R&D projects. Indeed, the result may have implications for many data collection instruments in the broader I/O psychology area.

3.4.4 Implications of TDS for Occupational Analysis and I/O Psychology

Many of the specific technologies developed or refined in the TDS R&D project might be useful to the existing state-of-the-art methods of occupational analysis in particular and

I/O psychology in general. The modeling of an occupation done in the TDS could be very beneficial to OA programs as a tool for better communication on the variety of jobs and training programs present in most specialties. Job descriptions using TMs are more concise that complete task lists, and managers can more quickly grasp the similarities and differences that exist among the jobs of an occupation (AF specialty). The U&T pattern simulation is a more dynamic representation of current reality in a specialty than the present static displays of job membership (Mitchell, et al., 1987). This aspect of the TDS could be constructively implemented in the operational OA program of the Air Force (and indeed, of all the military services) today, without waiting for the TDS refinements to be developed in the next R&D project. Likewise, our findings on data collection formats, targeted sampling, and task clustering could also be used immediately.

The task clustering programs built into the new ASCII CODAP system are a good example of immediate implementation of a TDS-inspired technology which has been made operational (Hand, Haynes, & Weissmuller, 1989). As further techniques are developed and operationally tested, they might also be incrementally implemented (see for example, the automated job and task cluster programs presently being tested; Mitchell and Phalen, 1985; Phalen and Mitchell, 1987; Mitchell, Phalen, Haynes, & Hand, 1988; Phalen, Staley, & Mitchell, 1988).

3.4.5 Implications of New R&D Technologies for the TDS

As noted earlier, new ASCII CODAP technologies have been developed and implemented for identifying task modules, cases characteristic or representative of task module performance, and displaying the joint performance distribution of task modules and case clusters (jobs). These technological improvements occurred after the TDS analysis of specialties had been done, and thus were not available at the time. However, these new technologies should be used in any future TDS studies, to make use of new state-of-the-art methods (and perhaps to provide a realistic operational test and evaluation of the new procedures). This kind of testing interaction between AFHRL R&D programs can provide considerable benefits to both programs, and to the Air Force MPT community as a whole.

In this light, we need to be aware of emerging technologies as they are being developed, in order to make optimum use of new methods. For example, the USAFOMC has requested research into interactive survey administration techniques, which would utilized Air Force personnel information networks to download survey instruments to base level, where surveys would be completed on unit microcomputers (PCs). If this technology is developed reasonably soon, it might be employed in the TDS to insure more timely collection of required TCS, FUS, and RCS data, as well for enhancement of the targeted samples needed for some types of information. By using real-time, operational Air Force personnel records to locate personnel and personnel communications networks to administer surveys, the TDS data collection could be made much more efficient and time lost in mailing time and failure of sampling (due to reassignments) could be eliminated.

This is but a single example of possible future interaction between the TDS and other AFHRL R&D programs, where the use and testing of state-of- the-art new methods can benefit both programs. Since there are a number of such R&D projects currently underway which deal in one fashion or another with the same general MPT areas as are addressed in the TDS, there are a substantial number of potential interactions which might be possible and fruitful. We need to examine some of these possible R&D project interactions in more detail; several are discussed in some detail in the following chapter.

4.0 POSSIBLE INTERFACE WITH OTHER R&D PROJECTS

Several of the most relevant AFHRL R&D projects which might have a significant interface with TDS technology are discussed below.

4.1 The Advanced On-the-Job Training System (AOTS)

The AOTS project developed a computer-based system that automates job site training functions and integrated the related management functions (Buescher, Olvera, & Besetsny, 1987). The initial prototype effort has completed three phases of design, development, and test and evaluation. The prototype was developed at Bergstrom AFB, TX to support some of the jobs in the Aircraft Maintenance and Security Police career fields. The AOTS R&D project was designed to provide incremental products, including training requirements definition processes, task proficiency evaluation procedures, training resources identification procedures, and automated training records (Ibid).

4.1.1 Basic Components of AOTS

The AOTS has five major subsystems which address OJT management, evaluation, curriculum development and delivery, computer support, and personnel support. AOTS is a *task-* and *job*-based system. A master task list for the specialty is used as a basis for specifying tasks to be trained; a number of generic positions (jobs) are recognized which involve the performance of somewhat different sets of tasks. In addition, individual OJT supervisors may identify additional tasks from the master task list or may specify new tasks required for a single position [new tasks are theoretically fed back to the USAF Occupational Measurement Center (OMC) for inclusion in future Task Inventories]. The generic position task list plus any unique or new tasks (minus any task training received in a formal course, such as the ABR) are the tasks which the OJT supervisor/trainer will train a given individual. Task performance will be tested and a complete task-by-task record of training is created. This training record will follow the individual airman throughout his or her career.

4.1.2 Interface with the TDS

Since both AOTS and TDS are concerned with the tasks and jobs of individual specialties, they generally use a common starting point--the AFS task list developed by the USAFOMC. In the AOTS R&D, the OMC task list was the starting point for development of the AFS Master Task List. However, where the OA program and TDS are concerned with identification of the major variations in the jobs of an AFS, the AOTS R&D effort focused on the specific content of jobs located at one base (one major command, one mission, etc.), since that is the issue for OJT trainers.

Fortuitously, TDS researchers were able to help identify generic positions and generate initial job descriptions from OSR data for use by AOTS developers in developing their generic position descriptions. Given the available data, some job descriptions were specific to the base; others were more generic (based on similar missions and organizations). AOTS SMEs refined these job descriptions and used them as a basis for developing OJT instruction, performance tests, and their records and management system.

Since the TDS and AOTS have a common starting point (OSR data on tasks and jobs of a specialty), they have much more potential for interface than most R&D programs. Ideally, the TDS could be used to identify the major jobs (generic positions in AOTS terms) and would provide information on the task (or task module) content of formal training programs for the initial set up phase of AOTS. The AFS current U&T model of the TDS could serve well for guiding needed development in creating the AOTS data base. Indeed, for the prototype R&D, TDS researchers retrieved CODAP data files for the AOTS specialties and reprocessed data where needed; the relevant CODAP data was exported from the AFHRL UNISYS to the VAX computer equipment supporting AOTS.

One major difference in TDS and AOTS is their different level of analysis; TDS operates at the Task Module (TM) level where AOTS presently manages OJT instruction, testing, and records-keeping at the task level (which becomes very complex for highly technical or diverse specialties, which can have 500 to 2000 tasks). Given the very large number of jobs and tasks involved for all the positions (in all AFSs) at a base, it might be wise to explore the possibility of managing OJT in AOTS at the TM level. If the tasks of TMs do capture the same skills and knowledges (as asserted in the TDS R&D) this would simplify records-keeping, expedite development of OJT instruction and testing, and ease the burden of detail on OJT trainers and supervisors. [Note: the initial AOTS design included provision for capturing the identity of which tasks belonged to which TMs for each AFS. This design feature would expedite development of TM-level management of AOTS task module training.]

As AOTS is implemented operationally and data files compiled, much of the AOTS data could be extremely useful for future TDS studies. Since AOTS will have specific data on trainer and trainee time spent on task training, that data can be summated to the TM level to validate and refine the training time estimates now used in the TDS. Additionally, AOTS would eventually generate data on training resource requirements and availability at a level of detail which also would be useful in the TDS [At present, the TDS would be able to estimate which resources are used in such training and which are critical as training constraints]. Likewise, AOTS data, summated across types of bases and missions, would greatly refine TDS identification of representative sites, the jobs involved in each such site, and verify job task (TM) content. Conversely, the TDS system costing of OJT could serve as the initial AOTS costing system until more specific cost accounting procedures can be developed for AOTS. Once developed, such AOTS cost accounting results could validate TDS estimates of OJT or be used as refined inputs for computing total AFS training costs.

The TDS is able to model changes in tasks, jobs, and training programs of an AFS, and to predict the cost consequences and training constraints resulting from the proposed changes. This would provide AOTS with a much quicker adaptation and update capability since any changes (in tasks, jobs, and training programs) would be directly and immediately implementable for OJT in a compatible data base.

These two R&D efforts have much to offer each other, if the potential interfaces are developed systematically over the life of both projects. This will require considerably more interaction between R&D staffs and project managers than was previously necessary (or possible). Since both projects are managed by AFHRL/ID, such future systematic interface is both possible and highly likely, once the potential benefits of such interaction are demonstrated and verified.

4.1.3 Recommendation

The potential interfaces between AOTS and TDS should be developed systematically and aggressively in any future R&D efforts. The potential management of AOTS at the Task Module level (vice task level) should be explored as soon as possible to make AOTS management of OJT simpler and less expensive. The potential use of AOTS data to validate and refine TDS predictions of OJT costs, selection of representative bases, quantification of training resource requirements and availabilities, and other factors should be programmed as a requirement of all future AFHRL R&D projects in both areas. The potential use of TDS in the training requirements analysis phase of AOTS projects (i.e., use of TDS AFS models and data on proposed AFS changes) should be an AOTS R&D contract specification.

4.2 The Job Performance Measurement System (JPMS)

In response to a Congressional request to validate selection tests against job performance, the DOD established a Joint Service Committee on Performance Measurement (JSCPM). The Air Force role in this effort has been the development of a task-specific Job Performance Measurement System (JPMS). Primary objectives of this research have been to construct job performance measures that are as free as possible from measurement bias and do so based on a conceptual model of job performance in the Air Force (Dickinson, 1986; Kavanaugh, Borman, Hedge, & Gould, 1985, 1987).

In the Air Force JPMS, the basic job performance criterion consist of measures of task performance; other JPMS measures under study include a Walk-Through Performance Test (WTPT), four rating forms to be completed by incumbents, peers, and supervisors, and several more global job dimension or job worth rating forms. The hands-on measures compromise the criterion against which the other measures are being evaluated as surrogate indices of performance (Bierstedt, 1985).

4.2.1 Job and Task Assessment

The WTPT focuses at the job level and several WTPTs are required for each specialty (for each type of jet engine, for example, in the Jet Engine Mechanic career ladder). The test consists of two parts; a hands-on test of task performance and an interview test of the steps involved in performing the tasks. Tasks tested were selected based on occupational analysis data under a systematic task selection plan (Alba, et al, 1985). Tasks were selected for each of four specialties to provide coverage of some tasks commonly performed by most incumbents, and other tasks specific to significant within-specialty job groups. Both the hands-on and interview test items were developed based on a detailed task analysis of on-the-job performance objectives derived in field visit observations and interviews with senior technicians at representative bases. Such data were translated into step-by-step performance measures for each task. The tests were administered in the job location by third-party evaluators who are not only subject matter specialists in the field but who were also intensively trained on rating procedures and the standards of successful performance for each step. In addition to scoring incumbents on each step of the task, the evaluators also record the amount of time it takes each incumbent to complete each task (Driskill, Mitchell, & Ballentine, 1985).

Preliminary analysis of results indicated a components of variance interrater agreement of .90 for evaluators of Jet Engine Mechanics performance (Bierstedt 1985). In addition, a repeated measures ANOVA indicated no differences among raters although there were significant differences among incumbents on performance, as expected. Analyses of other measures are still in progress.

Procedures developed in this research effort will be used in the validation of the present Armed Service Vocational Aptitude Battery (ASVAB) against job performance and technical school performance. This major research effort represents a methodological breakthrough in the area of criterion measurement, and the job performance measures developed have considerable potential for use in other Air Force MPT research efforts.

4.2.2 Job Performance As A Criteria For Evaluating Training Effectiveness

One of the areas where Air Force JPMS data could be useful is the area of evaluating the effectiveness of USAF training programs. This possibility was examined in a conceptual study during the summer & fall of 1985 (Driskill, Mitchell, & Ballentine, 1985). These authors concluded that with some modification, JPMS data would be extremely valuable as a criterion for a variety of training evaluation uses. In addition, they developed a training evaluation model based on the job performance model of Kavanaugh, Borman, Hedge, & Gould (1985, 1987). Such models may serve as a basis for innovative new research efforts in assessing the impact of various training programs on job performance and, ultimately, their utility in terms of combat readiness. Such research would require, however, a considerably more detailed knowledge of tasks and how they are accomplished in the operational environment.

4.2.3 Job Performance Measurement in AOTS and TDS

The techniques used to measure task performance in the JPMS project were applied to a large degree in the development of task qualification assessment in the AOTS project. AOTS, however, requires development of task performance tests for every task in the AFS, where JPMS measures are only a sampling of AFS tasks. Given the eventual creation of task performance measures for all AFS tasks in AOTS, this would greatly facilitate development of sample task measures for JPMS, and make development of the more detailed JPMS measures more cost-effective.

The use of JPMS technology in AOTS task measurement development is an excellent example of technology transfer between AFHRL R&D projects. Indeed, in this case, some of the personnel originally involved in JPMS procedural development later worked on the AOTS project.

In the TDS, there is presently no role for job performance measurement, since performance assessment is not considered in the AFS model or in the costing system. However, since task measurement is a real component of OJT programs (as demonstrated in the AOTS), the costs of such task assessment are an additional cost element which could and should be included in TDS cost estimates for AFS training. As the costs of task performance measures become visible in the AOTS, they should be added to TDS cost models.

In addition, if JPMS measurements are eventually implemented to assess training effectiveness (as recommended in Driskill, Mitchell, and Ballentine, 1985), then these measures may also be relevant for TDS. TDS could be used to model alternative training strategies for those areas where JPMS measurement suggest ineffective training. ATC or AFHRL could also experimentally vary training methods (formal school versus FTD versus OJT) and evaluate these alternatives not only in terms of training effectiveness but also in terms of total training costs and OJT capacity constraints, through the TDS. Specific experimental designs and methodologies would need to be carefully designed for such an "experimental school house."

4.3 Small Unit Maintenance Manpower Analysis (SUMMA) System

Small Unit Maintenance Manpower Analyses (SUMMA) is a system of models for optimizing aircraft maintenance task and specialty allocations. The SUMMA system has been described in detail by Moore, Wilson, Seman, Eckstrand, Lamb, and Lindeman (1987); Lamb, Eckstrand, Seman, and Lindeman (1987); Wilson, Faucheux, Gray, Wilson, Lamb, and George (1987); and Lamb, Eckstrand, Seman, Lindeman, Faucheux, Gray, Wilson, and Boyle (1988). SUMMA is intended to be a tool for "identifying and evaluating alternatives and for selecting ways to improve the Air Force's enlisted maintenance task/specialty structure (Lamb, et al, 1988)". SUMMA "integrate[s] manpower, personnel, and training issues in a single analytical, integrated system of models (Lamb, et al, 1988)". As these quotes suggest, the overall purpose of SUMMA is to help determine the best AFS structure to support aircraft maintenance, or the best assignment of maintenance tasks to AFSs.

A major motivation for the SUMMA development is dispersed basing of aircraft. Currently, large numbers of aircraft (i.e., entire fighter wings) are located at single bases. In contrast, under dispersed basing, a fighter wing would be spread out across many small operating locations so that only a few airplanes are at any particular location. Currently, aircraft maintenance AFSs tend to be very specialized with respect to aircraft systems (i.e., 328X4, Avionic Inertial and Radar Navigation Systems Maintenance). As a consequence, many AFSs, and, thus, many airmen, are required to maintain a single aircraft. When many aircraft are at a single location, this type of AFS structure permits efficient manpower use. However, under the dispersed basing concept, this very system- specialized structure requires many maintenance personnel at each of the many aircraft locations and a much larger total number of maintenance personnel. Furthermore, maintenance personnel at dispersed locations would probably not be fully used; the current AFS structure does not permit efficient use of maintenance personnel under dispersed basing. SUMMA is a tool for determining an AFS structure that permits more efficient manpower use under dispersed basing, while being acceptable relative to manpower, personnel, and training (MPT) considerations and constraints.

4.3.1 Structure and Function

SUMMA has six major components. As with the TDS, the SUMMA components are concerned with data collection, data analysis, modeling, and optimization. These six components are:

1. Operational and Maintenance Scenarios--The first step of a SUMMA study involves defining basing plans, missions, aircraft, and related operational features. Maintenance features, such as non-manpower support resources available, and maintenance and manpower utilization policies are also defined for each scenario to be studied.

2. Task Identification and Analysis--Lists of maintenance tasks are developed for each operational and maintenance scenario. Candidate tasks are formed by pairing each of seven standard maintenance action verbs with each equipment item on the subject aircraft type. These task candidates are then screened to eliminate meaningless and irrelevant tasks and to reduce the total number of tasks. Non-hardware oriented and support equipment tasks are added. Next, scores are obtained for each selected task on 24 task factors. including such factors as level of difficulty, how skill is acquired, and how long can this skill be retained without practice. Subject-matter experts (SME) provide the task factor ratings in structured interviews.

3. Manpower, Personnel, and Training Data--In this component, data are gathered concerning the current AFSs to be analyzed. Eleven categories of data are gathered, including (a) general and demographic variables, (b) requirements in 10 general knowledge areas, (c) education and experience requirements, (d) minimum ASVAB scores, (e) physical requirements, (f) training course characteristics, (g) special pay availabilities, (h) manning and rotation, (i) labor use rates, (j) skill upgrade times and costs, and (k) miscellaneous AFS requirements (i.e., security requirements). For the most part, these data are obtained from published sources and from the Occupational Research Data Bank (ORDB). Some are obtained from SME interviews.

4. Statistical Analysis--In this component, the data gathered in the previous three components are analyzed to form the SUMMA data base. Two analysis types are conducted--descriptive and cluster analysis. The descriptive analysis is primarily interrater agreement analysis of the SME ratings. The result is a set of profiles on appropriate variables for each task and AFS in the SUMMA study. In the cluster analysis, tasks are clustered based on (in some cases restructured) scores on the 24 task factors gathered in the second phase. The purpose is to find groups of tasks which might be new AFSs. The Ward clustering algorithm is used.

5. Decision Support System--The SUMMA Decision Support System (DSS) is a set of models and optimization analyses which use the data from the first four components, along with user inputs to find a best allocation of tasks to candidate AFSs. The DSS includes four types of models/optimizations: (a) a task allocation optimization model, (b) a detailed work flow model, (c) an MPT evaluation model, and (d) a cost evaluation model. The task allocation optimization model uses mathematical programming to assign tasks to AFSs so as to minimize aircraft down time and maximize manpower use rates, subject to constraints. The detailed work flow model both provides needed data to the task allocation model and is used to verify task allocation model results. The Air Force's Logistics Composite Model (LCOM) is used for detailed work flow modeling in SUMMA. SUMMA contains an interface to LCOM. The MPT evaluation model provides detailed analysis of MPT variables for an AFS structure, such as that developed by the task allocation model. Outputs from the MPT evaluation model include (a) manpower and manpower requirements statistics, (b) training pipeline manpower requirements, (c) recruiting statistics, (d) training length forecast, (e) Permanent Change-of-Station (PCS) move forecast, (f) On-the- job training (OJT) projection. The training length forecast computes the number of weeks in each AFS required for training in an Airman Basic Resident (ABR) course, in field training detachments (FTDs) and in basic training. The OJT projection analyzes the three-skill-level to five-skill- level upgrade process, including numbers of OJT hours required (based on data gathered in the second component) and numbers of weeks required to upgrade, taking into account the AFS manpower analysis. The cost evaluation model uses results from the MPT evaluation model to estimate the total basic military costs (basic pay and allowances) for the new AFSs, training costs for formal training, PCS costs, and recruiting costs.

6. Evaluation of Solutions--This component allows users to conduct sensitivity analyses and other evaluations of the DSS results and to generally modify and rerun various SUMMA analyses.

4.3.2 Comparison to TDS

Both SUMMA and TDS are MPT models designed to assist in identifying and evaluating alternative AFS structures. However, the two systems differ in many ways:

1. SUMMA is primarily driven by mission and manpower considerations --its primarily purpose is to find new AFS structures which improve sortie and manpower use rates. In contrast, the TDS is primarily training oriented--its main purpose is to evaluate MPT structures with respect to training impacts. The TDS focuses primarily on MPT structure within an AFS, while SUMMA contains little detail concerning within AFS structure and is concerned with between-AFS structure.

2. SUMMA is weapons system-oriented. It considers most or all AFSs that support a particular weapons system, but only those tasks in an AFS the relate to the specified weapons system. In contrast, the TDS is AFS-oriented. The TDS analyzes entire AFSs, including all weapons systems in an AFS, but typically examines only one or a few AFSs in a study. Furthermore, the TDS is not restricted to maintenance or systems-oriented AFSs.

3. SUMMA's stated purpose is to provide analysis in all three of the MPT areas, while TDS focuses primarily on training. The two systems are, in fact, much more similar in this respect than might appear. This is because a key part of the integrated TDS model is a manpower model--the FUS U&T pattern model. The real similarities and differences between SUMMA and the TDS in this respect can be seen by examining each of the MPT areas in more detail.

3a. Manpower--Both SUMMA and the TDS contain manpower models. In SUMMA, manpower modeling is done in the task allocation model, LCOM, and the MPT evaluation model. In TDS, the U&T pattern simulation is a manpower model. Both systems do manpower modeling and analysis, but the systems focus on different aspects of manpower. SUMMA derives manning requirements and use rates from mission requirements and operations/maintenance scenarios. In contrast, TDS models task performance requirements, but does not relate those to missions or use rates. The TDS model the flow of people through their entire careers, including job changes and training courses taken along the way. In contrast, SUMMA does not model career paths, except one standard first job career path, and ignores job differences. SUMMA treats all people at a particular skill level as the same.

3b. Personnel--SUMMA contains some personnel modeling features, although rather crude ones. TDS contains no explicit personnel modeling. Personnel characteristics of an AFS (i.e., aptitude scores) are assumed to be constant and to be reflected in other TDS data.

3c. Training--SUMMA contains training modeling features. These features allow training costs to be estimated for the three- to five-skill-level upgrade process, assuming no significant changes in training structure except those driven by a new AFS structure. For example, SUMMA assumes that tasks trained in an ABR course would continue to be trained to the same degree, although which tasks are covered in which AFS's ABR course might change. SUMMA does estimate pipeline manpower and calendar time for skill upgrading, considering other manpower use. The TDS contains detailed training modeling features. In contrast with SUMMA, the TDS focuses on position qualification training, rather than skill upgrade training. The TDS considers all previous formal and on-the-job training to estimate OJT quantities required for position qualification at each job change. The TDS is designed to study changed training structures. It permits trades to be examined among various training delivery methods, physical locations, course structures, and course attendees. The TDS considers student labor costs, instructor labor costs, and travel and per diem costs. The TDS estimates both labor and nonlabor training resource requirements and permits training capacity analysis. However, the TDS cannot estimate training resource availabilities as a function of manpower availability and mission requirements, as SUMMA can.

4. SUMMA and TDS have many similarities in the data gathering and analysis methods. For example, both systems use the same statistical clustering algorithm to find task groups. However, different data are used for this clustering and the task groups have different purposes in the two systems.

4.3.3 Recommendations

We believe that SUMMA and TDS, although different, can be highly complementary. Each attempts to take an integrated approach to MPT analysis, although for different stated purposes. Each contains detailed modeling features not contained by the other. In manpower, SUMMA explicitly derives manpower requirements from mission requirements. The TDS does not. However, the TDS explicitly models job differences and changes and career flows, while SUMMA does not. SUMMA contains explicit personnel modeling features, while the TDS does not. SUMMA contains relatively undetailed training analysis compared to the TDS. TDS permits detailed trade analysis on training structures, but does not estimate training pipeline manpower requirements or impacts on OJT of changing mission requirements. We believe TDS and SUMMA features could be integrated into a single model. Furthermore, certain features, such as more sophisticated personnel modeling, which neither TDS nor SUMMA have could be put in the integrated model.

4.4 The Integrated Simulation Evaluation Model Prototype (ISEM-P)

The Integrated Simulation Evaluation Model Prototype (ISEM-P) is a computer program, written in the SIMSCRIPT II.5 language, which simulates the basic planning activities and decision-making procedures involved in the Air Force Manpower and Personnel System (AFMPS). It contains a dynamic modular representation of the AFMPS in which aggregate manpower planning, training program management, detailed personnel assignment scheduling, and actual personnel flows are characterized as integrated, interdependent activities that determine the status of groups of Air Force personnel, and thereby control the evolution of the force structure over time (see Rueter, et al., 1981). ISEM-P has been designed as a prototype for a large-scale model that would serve as an analytic tool for predicting and evaluating the impacts of changes in policies, procedures, and environmental conditions on the performance of the entire AFMPS.

4.4.1 Overview of the Air Force Manpower and Personnel System (AFMPS)

The AFMPS is responsible for the procurement, development, maintenance, and deployment of the human resources available to the Air Force. Thus, it exercises substantial control over the fundamental characteristics of occupational life in the Air Force: where people are stationed, what jobs they perform, and what training they receive. The AFMPS also influences entry into and exit from the service through the actions it takes at the control points associated with airman and officer procurement and retention. Through these decisions, it provides the essential link between people and jobs that enables the Air Force to accomplish the objectives established in the Five-Year Defense Plan (FYDP).

The AFMPS is operationally partitioned into three components: manpower, personnel, and training. The manpower component is responsible for determining the effective demands for skilled personnel in various occupational specialties, at various levels of expertise and authority. The personnel component is responsible for maintaining adequate supplies of personnel who have suitable skills and experience, and who are appropriately located geographically to satisfy the demands defined by the manpower component. The training component is responsible for recruiting and developing personnel to replenish or augment existing supplies, and furnishing the education that enables current personnel to acquire new skills and become more proficient at old ones. Through such actions, a dynamic mechanism is provided for reconciling skilled personnel supplies and demands over time.

4.4.2 Comparison of TDS and ISEM-P as Models of the AFMPS

Obviously, the three components of the AFMPS are interrelated, and their performance can be highly interdependent. Modification of the procedures employed by any one of the components can have substantial effects on the ability of the other components to fulfill their responsibilities. Thus, it is important to incorporate essential features of all three components within any model intended to aid decision-making relating to the AFMPS.

In this regard, the Training Decisions System (TDS) focuses on the training component of the AFMPS, and models that component in considerable detail. In particular, the TDS develops specific training programs expressly designed to prepare individual people for the specific jobs to which they are assigned as they progress through careers within a single Air Force Specialty (AFS). The manpower and personnel components of the AFMPS, however, are represented only implicitly in the TDS, within the transition probabilities describing the flows of personnel between jobs in the specialty.

In contrast, ISEM-P contains more explicit representations of Air Force policies and procedures affecting the size and composition of the stock of personnel and the movements of personnel between assignments. It includes numerous specialties and substantial geographic detail. It operates at a much higher level of aggregation than the TDS, however, with regard to specialties, people, jobs, and training programs.

4.4.3 ISEM-P Structure

ISEM-P is an aggregate model. It deals with groups of personnel rather than individuals. Every personnel group is characterized by one or more of five attributes: skill, grade, year group, base, and time-on-station.

Skill is designated by a code indicating the type of job a group of personnel is capable of performing. ISEM-P skill codes correspond fundamentally to the AFSs used by the AFMPS to categorize occupational expertise. However, most ISEM-P skill codes constitute mergers of several AFSs. Altogether, there are 51 airman skill codes and 40 officer skill codes included in ISEM-P. Within each skill, personnel are stratified by grade, or rank. As with the skill codes, an ISEM-P grade usually represents more than one actual Air Force grade. ISEM-P includes five grades for airmen and five grades for officers.

A year group specifies the number of years a group has served in the Air Force, and is essentially analogous to the AFMPS measure of Total Active Federal Military Service (TAFMS). Thirty year groups are delineated in ISEM-P.

Each base in ISEM-P represents an actual Air Force base. It possesses all pertinent geographic, organizational, and tour-length characteristics of its real counterpart. The missions assigned to the simulated bases correspond to the missions attached to the analogous real bases, and the groups of personnel associated with the simulated bases conform to the personnel actually assigned to the applicable mission functions at the real bases. In total, 17 bases are included in ISEM-P. Of these, 13 are located in the Continental United States (CONUS), two in Europe, and two in the Pacific. Moreover, of the 13 CONUS bases, three are affiliated with the Air Training Command (ATC), three with the Military Airlift Command (MAC), three with the Strategic Air Command (SAC), and four with the Tactical Air Command (TAC).

Time-On-Station (TOS) is the number of months a person has resided at a base. This property is used by the AFMPS to determine when the person may be, or must be, moved to another base. Within ISEM-P, a TOS frequency distribution is dynamically maintained for each personnel group at each base.

Thus, the structure of the personnel force at any time is represented in ISEM-P in terms of the composition of the stock of personnel relative to the preceding five properties: skill, grade, year group, base, and TOS. These are the basic dimensions within which the representations of Air Force decision rules contained in ISEM-P operate. The representations of decision rules included in ISEM-P are all essentially deterministic. Stochastic, or random, elements have been included in only a few simulated decision rules as default conditions.

4.4.4 ISEM-P Operation

Six basic types of decisions routinely made by the AFMPS are represented in ISEM-P. They are: personnel authorization decisions, airman and officer procurement decisions, promotion decisions, training decisions, transfer decisions, and separation decisions.

The first five types of decisions are organizational decisions expressly taken to promote the objectives of the AFMPS. Conversely, the last type, separation decisions, are principally actions taken by individual Air Force personnel to serve their own private interests. They are not directly determined by the AFMPS, and hence may or may not be compatible with AFMPS objectives. Management decisions are made at numerous levels in the AFMPS, including the Air Staff, major command, and base levels. Each level operates on a different time scale, considers a different planning horizon, and uses a different aggregation of the force structure in its decision-making.

Two levels of decision-making are represented in ISEM-P. They have been implemented as two distinct submodels: the aggregate submodel and the assignment submodel. The operation of these submodels is explained in the following sections

4.4.4.1 The Aggregate Submodel - The aggregate submodel operates on a yearly cycle. It develops and actuates long-range force structure plans for a horizon period corresponding to the end of the current simulated year. In this planning process, the stock of personnel is described in terms of an array called the inventory, whose three dimensions are skill, grade, and year group. At the start of each submodel cycle, the inventory describes the population present at the beginning of a simulated year. Each cell in the array indicates the size of the group having the skill, grade, and year group properties that index the cell.

Within ISEM-P, the FYDP is represented as five yearly mission plans and five annual authorization ceilings. The mission plans summarize the programs included in the FYDP by stating which missions are to be attached to which bases during each simulated year. The authorization ceilings, conversely, express the budgetary restraints specified in the FYDP in terms of the authorized end-strengths for airmen and for officers in each simulated year. Authorized end-strength is the maximum total number of personnel allowed to be in the force performing mission functions at the end of a year.

Three principal AFMPS policy directives are embodied in the submodel. When total manpower requirements exceed authorization ceilings, manpower policy establishes the priorities attached to different skills in determining detailed authorizations. Next, Air Force promotion policy stipulates, for each grade, the specific year groups from which promotions into the next higher grade may be drawn. Finally, the equal promotion opportunity policy requires that all airmen in any grade are eligible for promotion on the same terms regardless of the skill in which they have been trained. Representations of all three of these policies are incorporated into the simulated decision rules contained in the submodel.

The aggregate submodel operates in two phases: the planning phase and the flow phase. Thus, for each simulated year, a year plan is formulated based on the initial inventory and the mission plan for that year. Then, the year plan is executed on the inventory to produce simulated personnel flows. The resultant array describes the inventory at the end of the current year, which, of course, corresponds to the initial inventory for the next submodel cycle.

More specifically, each simulated year the aggregate submodel receives as inputs the mission plan and authorization ceilings for that year, and proceeds to perform five basic operations. In these operations, the submodel first converts the mission plan into manpower requirements and, then, transforms the requirements into detailed authorizations. Next, it projects the expected state of the inventory after anticipated attrition. Third, it formulates promotion, training, and recruiting plans designed to change the state of the inventory to conform to the detailed authorizations. It then removes actual separation losses from the inventory. Finally, it applies the formulated plans to the inventory. This process produces the inventory that serves as a primary input to the next annual planning cycle. The formulated plans and actual results are also passed as inputs to the assignment submodel.

4.4.4.2 The Assignment Submodel - The assignment submodel deals primarily with the geographic distribution of personnel. It operates on a monthly cycle. It develops and implements short-range plans for personnel flow among bases for a horizon period nominally nine months ahead of the current simulated month. In this submodel, personnel groups, identified by skill and grade, are distributed among the bases to derive the stock of personnel at each base, termed the base supply.

The base supply is described a two-dimensional array. Each cell in the array indicates for that base the size of the group possessing the skill and grade characteristics that index the cell. Each personnel group within each base supply is further stratified by time-on-station, as explained in Section 6.4.4.1. Personnel in training are accounted for in the enrollment of the school they are attending. Schools are located at particular bases, but their enrollments are not included in the base supplies of those bases.

The purpose of the assignment submodel is to simulate the decision procedures that produce the assignment orders that cause personnel to be transferred between bases. In most instances, interbase transfer decisions are based on deviations that arise between base supplies and the authorizations at the bases. Each ISEM-P base has an authorization, determined by the aggregate submodel during its planning phase, that specifies the desired number of personnel in each skill and grade that should be present at the base at the end of each simulated year.

In addition to the policy directives embodied in the authorizations and plans transmitted from the aggregate submodel, four other notable AFMPS policies are incorporated in the assignment submodel. Rotation policy establishes restrictions on the maximum permissible length of time personnel may serve at overseas bases. In addition, time-on-station policy specifies the minimum allowable tour length for personnel residing at CONUS bases. Third, in each skill and grade experiencing an overall shortage or surplus of trained personnel, world-wide manning level policy governs the sharing of that surplus or shortage among bases. Finally, interbase transfer policy defines the order in which different categories of personnel are selected for assignment to CONUS and overseas bases. The simulated decision rules included in the assignment submodel contain representations of all four of these policy directives.

Deviations between base supplies and authorizations can occur in the prototype for several reasons. The reasons include: separations, assignments of cross-trainees to schools, changes in mission plans or authorization ceilings, extraordinary assignment actions such as those involved in closing a base, and restrictions on the maximum length of time that personnel may serve at certain bases.

To eliminate deviations of base supplies from authorizations arising from any of these sources, the assignment submodel produces appropriate assignment orders and then executes the orders on the actual pool of personnel. Execution of an assignment order effects the flow of a group of personnel through a school or from one base to another.

Like the aggregate submodel, the assignment submodel operates in both a planning phase and a flow phase. In each simulated month, the planning phase creates assignment orders based on its projection of base supplies for the horizon period nine months in the future. The flow phase then executes the assignment orders established nine months earlier for the current month.

More precisely, the assignment submodel converts the plans formulated for each simulated year in the aggregate submodel into month-by-month, base-by-base schedules for separations, promotions, and training assignments. It also schedules all transfers among bases necessitated by policies restricting the length of overseas tours, and allocates newly trained personnel to bases. The schedules are established for the horizon period on the basis of projections of base supplies and base authorizations for that period. Then, the schedules are applied to the actual base supplies to simulate the resultant flows of personnel through training and among bases.

ISEM-P assumes that all airman and officer procurement demands will be fulfilled, in terms of both quantities and aptitudes. In an analogous manner, separations in ISEM-P are completely controlled by an exogenously supplied set of separation rates for each group in the inventory.

4.4.4.3 The Consolidated ISEM-P System - The basic operation of ISEM-P, focusing on its two submodels and their interrelationships, is displayed schematically in Figure 6.1. This figure reveals a basic difference between the information-feedback opportunities available within the inventory and the base supply planning processes. Because the inventory planning horizon corresponds exactly to the length of the inventory planning cycle, each inventory plan developed in the aggregate submodel is based on the actual state of the inventory realized at the end of the preceding cycle. In contrast, the base supply planning horizon is equal in length to nine base supply planning cycles. Consequently, each base supply plan formulated in the assignment submodel necessarily depends on the plans and projections developed for the eight intervening months between the current simulated month and the planning horizon. The resultant difference in information-feedback mechanisms is highlighted in Figure 6.1, where a single integrative feedback loop appears within the aggregate submodel, while two essentially independent loops are depicted for the base supply planning and base supply flows portions of the assignment submodel.

There are 12 monthly cycles of the assignment submodel for each yearly cycle of the aggregate submodel. The entire process is iterated through the total number of simulated years, typically five, for which input data are provided in ISEM-P.

Taken together, the two component submodels of the prototype simulate the interaction of many of the goals, objectives, and constraints of the AFMPS. However, as explained above, each submodel addresses a distinct subset of those concerns; and even where both submodels examine the same issue, the manner in which the issue is resolved may vary.

4.5 Training Analysis Support Computer System (TASCS)

The Training Analysis Support Computer System (TASCS) is a microcomputer-based Instructional System Design (ISD) tool (Logicon, 1985). Its purpose is to support detailed task analysis and training system design. It is intended for use by instructional systems designers, working with subject-matter experts (SMEs). Task analysis, as used here, refers to the process whereby job tasks are translated into training behaviors, standards, and conditions.

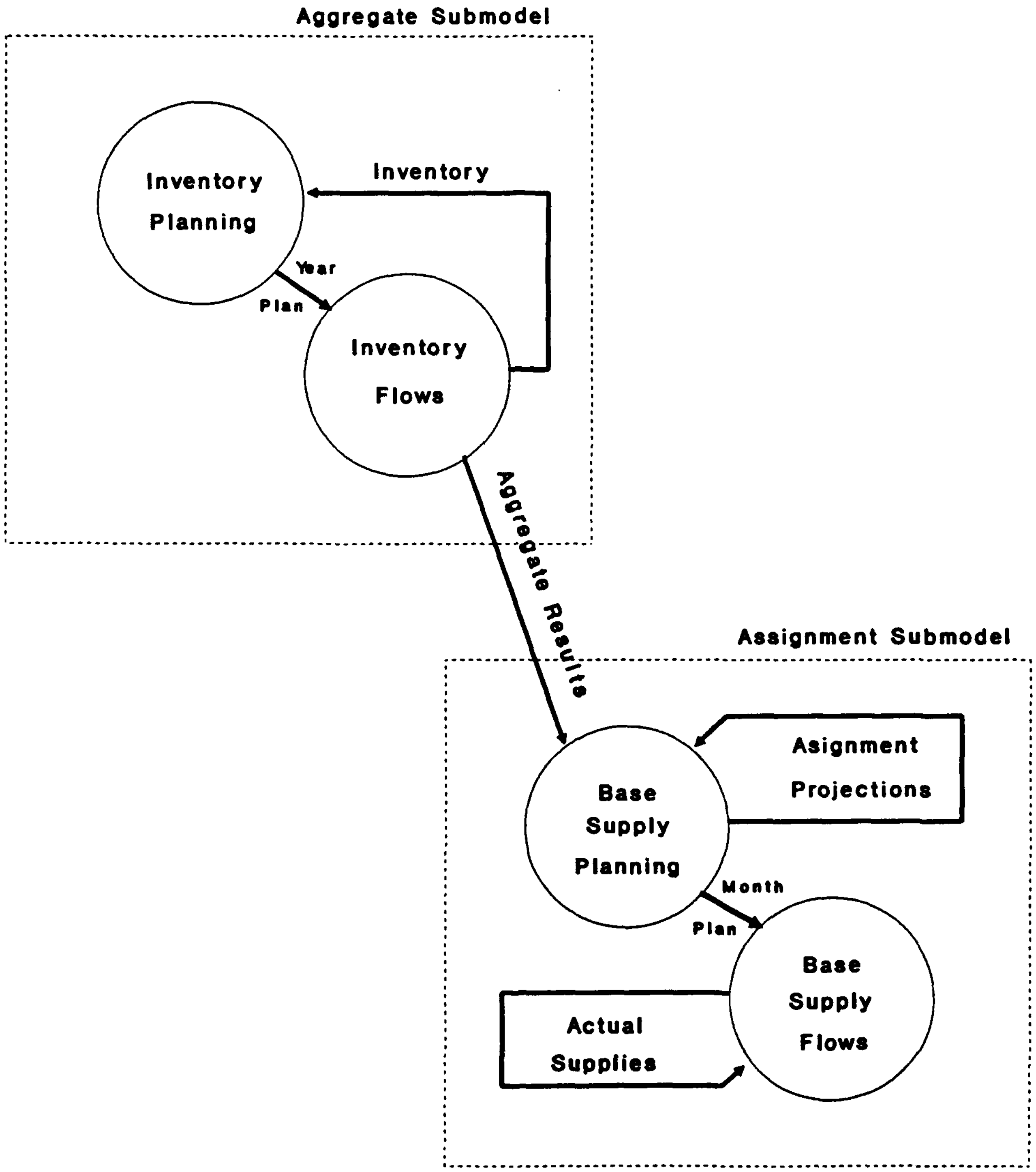


Figure 4.1 The ISEM-P Model

4.5.1 Relational Data Base Management

TASCS is primarily a task analysis data base management system. It was originally developed by Logicon, Inc. for the Air Force Ballistic Missile Office. It has since been refined under other Air Force contracts. The version described by Logicon (1985) was written in dBase III, a powerful general-purpose microcomputer-based relational data base tool.

4.5.2 TASCS Data Content

Logicon (1985) presented a number of reports generated by TASCS for the F16 task analysis. One such report is a training objective hierarchy. Another report presents the following information for each objective behavior:

1. objective training sequence
2. conditions under which behavior is performed
3. performance measures and standard
4. proficiency level
5. performance frequency
6. performance cues
7. who performs
8. learning subcategory (list of standard categories, i.e., remember facts, use aided procedures, use unaided principles)
9. difficulty rating and reasons for difficulty
10. safety and mission criticality
11. related systems and facilities
12. time to perform
13. job code
14. team
15. source
16. remarks

In general, these data are entered into TASCS by instructional designers in consultation with SMEs.

4.5.3 Relationships with TDS

The TDS is not intended to service all ISD processes. Rather, the TDS supports decisions made early in the training development process (Step 1 and part of Step 2) that result in constraints within which the full ISD process must be done. As such, the TDS would be used before TASCS; TASCS would be used to support curriculum development after certain decisions are made using the TDS.

Some of the data entered into TASCS can be obtained from the TDS or the occupational survey data base. Examples of these data include proficiency level, difficulty, frequency, and criticality. If TASCS were to be used in conjunction with TDS, as suggested here, it would be advantageous for certain TDS data to be input directly and automatically into TASCS.

4.6 Other Air Force Modeling R&D

The Air Force manpower, personnel, and training (MPT) community could make use of the TDS technology in many different areas. One area of primary interest to AFHRL would be the potential use of TDS in support of Air Force MPT modeling. Several potential applications are described below.

4.6.1 Time to Proficiency (TTP) Model

Under contract with several contractors, AFHRL has developed a modeling tool that could be useful to personnel and manpower planners in selecting optimum qualification scores for classification into an Air Force Specialty (AFS). This model tool was developed originally by Monaco and Carpenter (reported in Monaco, et al., 1989) as a demonstration of using a learning curve to measure proficiency and serving as a predictor of productive capacity. The original model has been improved and extended by Stone and his coworkers (Stone, et al. 1989) to include optimization over multiple AFS's with a computerized prototype. This tool shows remarkable promise for the ability of manpower and personnel planners to use productive capacity and cost as good measures to set minimum qualifications for AFS classifications.

The costs used in the development of this model, however, suffer from lack of differentiability across AFS's and show little effect of differential training patterns. An ideal match for the enhanced usefulness of the TTP model would be a combination of the TDS and TTP into a single policy tool that could be used to set minimum qualifications for classification standards and also explore the effect of alternate training patterns on the classification standards. Although this combination would take a great deal of programming effort, an earlier version could be developed that summarized several training patterns for the AFS's currently used in the TTP model, and that information about costs could be used to enhance the existing TTP model.

4.6.2 Person-Job Match Modeling

The Air Force has been using decision modeling techniques to determine optimal job classifications of recruits for some period of time. The earliest reported version of an optimal batch assignment model had been developed and reported on in Ward (1959) and Bottenberg (1962). This process used a linear programming methodology to allow classification clerks at Lackland AFB to assign graduates of Basic Military Training (BMT) to formal training slots in some optimal fashion, based on availability of slots and time of graduation. Another attempt at optimal classification involved a formal computer model, the Training Line Simulator, developed by Hatch, et al. (1974) using modern linear programming methodologies to perform this same process. The training line simulator was later replaced with a non-optimal assignment process called the PACE system, which is still in effect today for all classification decisions made during BMT.

The decision index developed by Ward (1959) was later used by Ward and Haltman (1974) to form what was to become the Procurement Management Information System (PROMIS). In the PROMIS software package, the Air Force was able to combine decision modeling with optimization techniques to allow for a sequential classification algorithm to be used prior to enlistment. The fully developed PROMIS system (described in Ward, et al., 1979) is basically the system still in use today by the Air Force Recruiting Service to perform the initial classification decision for approximately 50% of the enlistees into the Air Force. The other 50% of the classification decisions are still made in non-optimal form using PACE. Some work which is as yet unreported is currently going on at AFHRL to define a post-enlistment classification process which would replace the PACE system with a batch assignment algorithm that used some of the optimization features of the PROMIS, but the cost of training will not be included in this optimization process.

With the development of TDS, the Air Force has an opportunity to take advantage of a significant advance in the state of the art in classification modeling. The TDS software in its current configuration could be readily modified to be used to assist in the post-enlistment person-job match process. The decision to classify and train an enlistee today is made without regard to the cost or effectiveness of the subsequent training, nor does the classification process allow for the consideration of different training patterns. By modifying TDS to be used in the post-enlistment process, the Air Force could make optimal classification and assignment decisions in the same process, and have the optimal process include differential training cost considerations in addition to the factors that are currently being considered by AFHRL.

4.7 MPT Modeling Integration

As noted above, the TDS might be used or adapted for a variety of purposes involving the modeling of Air Force specialties. If implemented as an extension of the normal occupational survey process, the TDS modeling would naturally support the U&T Workshop process (as now authorized by the new AFR 50-23, Enlisted Specialty Training, August 1990). By using the TDS and such AFS modeling to support its decision making, a U&T Workshop could not only formulate but also evaluate a variety of possible job and training configurations so as to optimize training (resident training, FTDs, OJT, etc.) in ways which would best meet the needs of the specialty.

By selecting or specifying the jobs and training programs of an AFS, the U&T Workshop would be performing its key management function, but would also be completing Step 1 of the ISD process. It would also be selecting (or refining) the appropriate Master Task List and Generic Position Task Lists needed as the initial phase of AOTS implementation for a career field. It would also be completing the initial phase of development of a Career Field Training Management Plan as recommended by the new AFR 50-23). Thus, implementation of the TDS could and should lead to the integration of several different R&D programs into an integrated operational program.

These various R&D programs are now being undertaken as separate, isolated projects. A more realistic approach would be to design a general integration of all MPT research initiatives which would aim at the long-term synthesis of the various systems into a coherent operational system. Such a strategy would also facilitate the identification of other areas where present R&D efforts do not yet provide needed advanced technology required for such an overall operational implementation. The TDS might well serve as the basis for such an overall plan and integration.

In addition, we need to examine the potential uses of TDS outside of its design environment; that is, in other potential applications beyond support of technical training decision making. One obvious possible application would be its use in the New Weapon System Acquisition process, and several requests have already been made by members of that community for development of such an advanced TDS capability. We should also explore other uses for TDS and training decisions modeling technologies within the Air Force (officer specialties, professional military education, etc.) as well as potential applications in other services, other DOD agencies, and transfer of this technology to the civilian world as well.

5.0 EXERCISING THE TDS

A major testing of the technology and the software involved in the proof-of-concept TDS was undertaken to identify any problems in the system itself or in its software. The objectives of this test were satisfied, some software problems were identified and corrected, and several areas of potential improvement were identified. This test of the system is discussed in detail below.

The Training Decisions Technology Analysis Research Plan specified that TDS software resident on the AFHRL UNISYS computer would be executed for the current U&T pattern and selected other patterns for the four TDS specialties, as a basis for displaying system capabilities, developing examples of products, and identifying any software problems. There were four major subtaskings involved in this major exercise of the TDS:

(a) run all TDS software programs, as well as selected options for optimization problems;

(b) enhance and refine the current version of the TDS software, identifying and correcting any software problems;

(c) document TDS analyses and optimization runs for the current and several alternative U&T patterns for each of the four TDS specialties; and

(d) develop a discussion of other impacts upon U&T specialties including the impact of constrained TDY-to-school resources upon relevant cost and capacity variables.

5.1 Approach and Results

The basis of this initial exercise was to employ procedures specified in the August 1988 Procedural Guide, TDS User Instructions (Task IV, CDRL 1:25), in order to check the validity of the instructions and to help identify any errors or omissions. As stated in the Research Plan, each specialty was to be tested using the current utilization and training pattern, the two or three alternate utilization and training patterns most preferred by field managers (as indicated in the earlier U&T Pattern Preference Survey administered in the original TDS R&D effort), and a U&T pattern that depicted a 25 percent reduction of personnel TDY to Field Training Detachments and other advanced courses (TDY-to-School funds). In addition, an alternative with 25 percent bypassing the ABR and receiving most of their training via OJT was examined. Therefore, each specialty actually involved modeling five or six different U&T patterns.

Results from the initial runs were then compared with the basic runs from the initial TDS R&D to assure that the system was operating properly. Several of these tests are described below.

5.1.1 AFS 423X1, Environmental Systems Maintenance Exercise

The capabilities of the TDS programs were exercised with AFS 423X1, Environmental Systems Maintenance. All AFS 423X1 data files resided on the AFHRL UNISYS equipment, with the exception of the TDY-to-school reduction and the additional model for reducing ABR attendance by 25 percent. Two new data files were created to model the TDY-to-school reduction and ABR reduction.

The approach taken for each U&T pattern was to put together one runstream for all subsystems of the TDS and have the FUS, TCS, and RCS outputs accomplished at one time. The UTPSIM program comprised the first part of the runstream, the TRNPRF program the second segment, and the RCS programs a third part. By exercising all programs at one time, we could compare errors or inconsistencies with the draft user's guide and identify corrections needed.

[Note: An example runstream used to produce U&T pattern reports and a complete set of reports for AFS 423X1 have been published in the TDS Examples report, a companion document for the TDS User Manual and the TDS Programmer Guide to provide examples of each type of TDS report. These examples are available from AFHRL/IDET, Brooks AFB TX 78235-5601.]

5.1.1.1 AFS 423X1 Exercise Problems - Some difficulties were encountered in the initial efforts to exercise the system and produce the AFS 423X1 TDS reports.

There were some unanticipated errors in example runstreams included in the August 1988 Procedural Guide, TDS User Instructions (Task IV, CDRL 1:25), which terminated the initial runs. Some of these were typographical errors made in preparing the Guide, which could be easily corrected. Others involved some disparity in the names and descriptions of two required data matrices; these errors were identified and corrected; they have also been corrected in a revision of the procedural guide (the TDS Programmer Guide, CDRL A007).

The RCS capacity programs, which had been improved on the CONSAD and MDC VAX machines since the final TDS Progress Review (Sept 1988), had not been fully upgraded on the AFHRL UNISYS equipment. Since there were still several known problems with this software, we decided these problems needed to be corrected before transfer of the upgraded software to the AFHRL equipment. Correction of these programs proved more difficult than anticipated and took more time than expected. The corrected programs were completed by 5 May 1989 and were uploaded to the UNISYS the following week. Such uploading includes recompiling the software using AFHRL-unique language; some difficulty was encountered in compiling one of the capacity programs which further delayed the process. As of 12 May 1989, all of the capacity programs had been successfully compiled and are now operational on the AFHRL UNISYS machine.

Some problems were encountered in identifying the appropriate files stored in the AFHRL UNISYS; during the original TDS R&D and the TDS training session, many runs were made which were still on the system. These many different runs were labelled in different ways, depending on which analyst had ordered the run and when the run was made (many of the runs made during TDS training or in preparation for the final TDS progress review had unique or abbreviated labels since they were temporary files). The amount of time since the files were last used was a factor, since some of the temporary file names had not been recorded or were not remembered adequately. The master listing of current files provided by AFHRL/IDET was very useful in resolving most of this kind of problem, but considerable research and testing was required to assure that the proper file had been identified and used in making runs. The number of files involved in multiple U&T patterns for each AFS makes the file inventory complex; we highly recommend that a systematic approach be used in naming TDS files [analogous to the CODAP conventions for file designations].

A related issue is the labelling of TDS products; the current software was set up in such a way that all U&T pattern products included a subtitle for "Current U&T Pattern" which, in this case, meant the pattern being analyzed in that particular run - the one being studied at that point. This became a problem when multiple runs were compared; to keep the various alternatives in mind, the analyst must refer to the initial page of the product and decipher the filename and then mark each product. A better approach would be to insert a unique title line for each run for a given U&T pattern. This would prevent any confusion in the identity of the AFS or U&T pattern being studied by having a clear text designator for the AFS and U&T pattern on the product.

5.1.1.2 <u>AFS 423X1, Environmental Systems Maintenance Results</u> - For the Environmental Systems Maintenance specialty, the following AFS models were developed and run:

a. Current U&T Pattern
b. Alternative 1 U&T Pattern (Two track - Tactical or Strategic/Airlift)
c. Alternative 2 U&T Pattern (Increased OJT/FTD Role)
d. Alternative 4 U&T Pattern (No Technical School)
e. Decreased TDY-to-school (modeled as 25% reduced flow into FTDs, PME, and advanced courses)
f. Decreased ABR Flow (25% direct to duty bypassing the ABR).

A review of the Current U&T Pattern and Alternative U&T Patterns 1, 2, and 4, indicated that results were comparable to data output in the basic TDS R&D (with minor variance where some known change had been made or error corrected). These data are available for review in the data runs enclosed with this report.

The two new AFS models (e. and f. above) are of particular interest, since they represent new tests of the TDS software with specified restrictions or changes to the current U&T pattern. To implement such changes, it was necessary to modify the data files for the specialties.

For the decreased TDY-to-school alternative, we elected to model this change as a decrease of .25 in the probability of attending an FTD course (there are no advanced courses in the AFS 423X1 TDS current U&T model). The file reflecting school attendance probabilities was located (in this case, a job-driven training file), and each probability reduced accordingly. PME attendance is reflected in a second file

(TAFMS-driven training file); these probabilities were also reduced by .25. Theoretically, these reduction in the proportion of airmen in a job attending an FTD and airmen in a TAFMS group attending a PME course, should equate to an overall reduction of 25 percent in TDY-to-school travel for this specialty. In practice, there will of course be some variation in results (plus or minus a percent or so) due to rounding or other computational factors.

For the reduced ABR attendance model, only one data matrix had to be modified; this is the entry file which reflects the average number of persons who enter the career field each month and how they are allocated (to ABR or to AFS jobs). Normally, for AFS 423X1, almost all (96%+) enter the career field by attending the ABR course; only a small number (normally individuals with prior service or experience) bypass the ABR and are given direct duty assignments (DDAs). Since the current U&T model already provided for some DDAs, the only changes needed to model this alternative were to decrease the probability of attending the ABR by .25 and to reapportion the flow of individuals directly into field jobs [a decision had to be made as to how to reapportion; we chose to use the same proportion for each job as in the current flow of DDAs. An alternative strategy might be to use the relative proportion of lst job personnel in each job times .25 to estimate the new DDA flow for each job.]

The results appear reasonable and understandable; the approach taken to modeling the change in the specialty appears to work reasonably well. Two tables comparing the current U&T pattern (as a baseline) to the alternatives are shown below to highlight the results (see Tables 5.1 and 5.2). The Formal School Costs portion of these tables was extracted from the RCS Cost Report for both the current and new U&T model; the OJT Costs were extracted from the second section of the same report. The totals and difference ($ and %) values were used to compile current and new U&T model reports to provide a summary comparison between these two alternatives.

25% REDUCTION IN TDY-TO-SCHOOL COSTS *

AFS 423X1, Environmental Systems Maintenance

(in Dollars)

	Formal School Costs				OJT Costs		Total AFS
	Trainee DTC **	Trainer DTC	Per Diem Costs	Transport Costs	Trainee OJT Cost	Trainer OJT Cost	Trng Costs Per Year
CURRENT U&T	962,000	119,031	662,635	387,111	334,470	221,253	$ 2,646,500
REDUCED TRAVEL	851,504	100,236	572,082	292,158	338,720	223,601	2,378,301
Difference	- 110,496	- 18,795	- 50,553	- 94,953	+ 4,250	+ 2,348	- 268,199
Percent Dif.	- 11.49%	- 15.79%	- 8.12%	- 24.53%	+ 1.27%	+ 1.06%	- 10.13%

* Modeled as a 25% reduction in the probability of attending an FTD, PME, or advanced course
** DTC = Direct Training Cost

Table 5.1 25% Reduction in TDY-to-School Costs

For AFS 423X1, a reduction in TDY-to-school funding would slightly increase total OJT costs for the specialty (about 1 percent) and would result in a decrease of about 10 percent in total AFS training costs per year. This reduced TDY-to-school model indicates that most of this savings is the result of reduced trainee and trainer time in the classroom; non-salary savings would be $94,953 in reduced transportation costs (24.5%) and an associated $50,553 in per diem (8.1%).

For the other AFS model (25 percent reduction in Basic Resident Course attendance), comparable data are shown in Table 5.2. There is a substantial savings in formal school costs, with the greatest savings being in per diem costs and trainee time. Note that in this specialty, the ABR is less than 12 weeks long and thus is considered an enroute TDY for students; thus, per diem is handled in a TDY-to-school account rather than normal operations and manpower (O&M) funding.

[Other AFSs, such as AFS 328X4, with longer than 12 week ABR courses, are handled as a permanent change of station (PCS); in such cases, travel and per diem are managed as O&M and are not included in TDY-to-school funding. Thus, the 17 percent savings in per diem costs is something of an artifact of the cost accounting system and the categorization of schools as either PCS or TDY enroute. For an AFS like 328X4 with a PCS school, such savings would not occur, or would not be visible.]

For the reduced ABR model, there is a substantial increase in OJT costs, as might be expected when 25 percent bypass the technical school.

25% REDUCTION IN BASIC RESIDENT SCHOOL FLOW *
AFS 423X1, Environmental Systems Maintenance
(in Dollars)

	Formal School Costs			OJT Costs	Total AFS		
	Trainee DTC **	Trainer DTC	Per Diem Costs	Transport Costs	Trainee OJT Cost	Trainer OJT Cost	Trng Costs Per Year
CURRENT U&T	962,000	119,031	662,635	387,111	334,470	221,253	$ 2,646,500
REDUCED ABR	831,241	107,538	516,482	378,665	376,971	236,976	2,447,873
Difference	- 130,759	- 11,493	- 106,153	- 8,446	+ 42,501	+ 15,723	- 198,627
Percent Dif.	- 13.59%	- 9.66%	- 17.05%	- 2.18%	+ 12.71%	+ 7.11%	- 7.51%

* Modeled as a 25% direct duty assignments (bypassing the ABR)
** DTC = Direct Training Cost

Table 5.2 25% Reduction in ABR Attendance

Note, however, that the increase in OJT trainee and trainer costs is only slightly less than the reduction in Formal School trainee and trainer costs, in terms of percentages. In terms of actual dollar values, the increase in OJT indicates much less of an increase in trainee time, but a greater gain than loss (over formal school) in trainer time. Trainees take less hours to learn the tasks involved on the job, but more trainer time and effort is required. The question becomes, then, one of whether the field units have the capacity to conduct the increased OJT required under this scenario. A training capacity analysis was conducted for

AFS 423X1 with results suggesting that there would not be any significant impact on the ability of the representative field units to conduct the increased OJT required by such a change. Since these results are not particularly significant, they are not included here; for illustrative purposes, the capacity analyses for AFS 328X4 are more worthwhile and interesting.

5.1.2 AFS 328X4, Avionic Inertial and Radar Navigation Systems Results

For the Avionics Inertial and Radar Navigation Systems specialty, the following AFS models were developed and run:

a. Current U&T Pattern
b. Alternative 1 U&T Pattern (Two track - Tactical or Strategic/Airlift)
c. Alternative 3 U&T Pattern (Versatile Workforce; Initial assignment to TAC with subsequent assignments to SAC/MAC)
d. Alternative 5 U&T Pattern (Specialization by system)
e. Reduced TDY-to-school U&T (modeled as .25 reduction in the probability of attending an FTD, PME, or advanced course)
f. Reduced ABR Flow U&T (25% bypass ABR for DDAs)

5.1.2.1 AFS 328X4 Training Cost Results - A review of the Current U&T Pattern and Alternative U&T Patterns 1, 3, and 5, indicated that results were comparable to data output in the basic TDS R&D (with minor variance where some known change had been made or error corrected). As with AFS 423X1, the two new AFS models (e. and f. above) are of particular interest, since they represent new tests of the TDS software with specified restrictions or changes to the current U&T pattern. To implement such changes, it was necessary to modify the data files for the specialties (as was done with AFS 423X1).

The results appear reasonable and understandable; the approach taken to modeling the change in the specialty appears to work reasonably well. Two tables comparing the current U&T pattern (as a baseline) to the alternatives are shown below to highlight the results (see Tables 5.3 and 5.4). The Formal School Costs portion of these tables was extracted from the RCS Cost Report for both the current and new U&T model; the OJT Costs were extracted from the second section of the same report. The totals and difference ($ and %) values were calculated by hand from the compiled current and new U&T model reports to provide a summary comparison between these two alternatives.

For AFS 328X4, the reduced TDY-to-school U&T option indicates a 25 percent savings of both transportation and per diem costs (see Table 5.3). In this case, since the ABR is a PCS course, there are no per diem expenses associated with the ABR; thus, the observed value for per diem for both the Current U&T and the Reduced Travel U&T both involve only FTD, PME, and advanced courses. Note also that while the increase in OJT Trainee dollar costs is somewhat less than the drop in Formal School Trainee costs, the opposite is true for Trainer costs (OJT vs Formal School). The overall impact on total AFS training costs per year in terms of percentage savings is relatively small (- 1.43%); however, we also need to be able to assess the impact of the added OJT responsibility for field supervisors (trainers). This involves an OJT capacity analysis, which will be reported later.

25% REDUCTION IN TDY-TO-SCHOOL COSTS *

AFS 328X4, Avionic Inertial & Radar Navigation Systems

(in Dollars)

	Trainee DTC **	Formal School Costs Trainer DTC	Per Diem Costs	Transport Costs	OJT Costs Trainee OJT Cost	Trainer OJT Cost	Total AFS Trng Costs Per Year
CURRENT U&T	1,545,437	159,318	12,614	326,587	3,441,468	1,003,679	$ 6,489,103
REDUCED TDY	1,466,011	146,903	9,183	242,796	3,507,167	1,024,022	6,396,082
Difference	- 79,426	- 12,415	- 3,431	- 83,791	+ 65,699	+ 20,343	- 93,021
Percent Difference	- 5.14%	- 7.79%	-27.19%	- 25.65%	+ 1.91%	+ 2.03%	- 1.43%

* Modeled as a 25% reduction in the probability of attending an FTD, PME, or advanced course
** DTC = Direct Training Cost

LN20COST328C.12-17-90 vs LN20COST328D.12-17-90

Table 5.3 AFS 328X4 Reduced TDY-to-school

For the 25 percent reduction in ABR flow (Table 5.4), note that this change has no real impact on the total AFS training costs per year (plus thirty-five hundredths of one percent additional cost). The greatest percent difference is a savings of about 19 percent in Formal School trainee hours; however, this is mostly offset by the 7.69 percent increase in OJT trainee hours. The most significant increase is the additional $81,491 of OJT trainer time required; this is over $54,000 more than the savings in Formal School trainer costs. It would appear that we are trading savings in Trainee time (salary) for the time of Trainers in the field; thus the availability of OJT trainers in operational units becomes the critical factor. This possible constraint needs to be assessed through a TDS capacity analysis.

25% REDUCTION IN BASIC RESIDENT SCHOOL FLOW *

AFS 328X4, Avionic Inertial & Radar Navigation Systems

(in Dollars)

	Formal School Costs Trainee DTC **	Trainer DTC	Per Diem Costs	OJT Costs Transport Costs	Trainee OJT Cost	Trainer OJT Cost	Total AFS Trng Costs Per Year
CURRENT U&T	1,545,437	159,318	12,614	326,587	3,441,468	1,003,679	$ 6,489,103
REDUCED ABR	1,252,644	132,646	14,092	320,888	3,706,166	1,085,170	6,511,606
Difference	- 292,793	-26,672	+ 1,478	- 5,699	+ 264,698	+ 81,491	+ 22,503
Percent Difference	- 18.94%	-16.74%	- 1.17%	- 1.74%	+ 7.69%	+ 8.12%	+ 0.35%

* Modeled as a 25% direct duty assignment (bypassing the ABR)
** DTC = Direct Training Cost

LN20COST328.12-17-90 vs LN20COST328T.12-19-90

Table 5.4 25% Reduction in ABR 328X4 Student Flow

5.1.2.1 Training Capacity Results - The Training Capacity Component of the RCS evaluates the capacities of various representative sites to provide training in appropriate settings on different combinations of TMs and in training volumes that are compatible with the U&T patterns identified in the FUS. Inputs to this component consist of the following: TM combinations and training volumes for the various U&T patterns (from the FUS), predicted amounts of specific resources required for the provision of training on each TM in each training setting (in the form of regression equations from the Resource Requirements Component), and availabilities of those resources for providing training at each representative site. Resource availability data are collected in a Training Resources Availability survey of TTCs, FTDs, and representative field units. For dedicated training resources, data on the sharing of equipment and other resources must be collected since sharing has a potential impact on training capability, and may vary by site.

An analyst develops estimates of the capacity of each representative site to accommodate various combinations of TMs and training loads, and identifies any resource limitations that constrain representative sites from accommodating particular U&T patterns. When such constraints are encountered, they are displayed in the OJT Capacity Report for each site as "Trainees Unsupportable" (see Rueter, Feldsott, & Vaughan, 1989)

Table 5.5 displays typical results of the AFS 328X4 training capacity analysis (for representative site 1). Note the training deficits of 18 trainees imposed by Resource 39 (aircraft), and 9 trainees for Resource 160 (weapons release control system analyzer), which are highlighted. These results indicate that the required amount of training cannot be provided at Site 1 because of a lack of enough equipment needed to conduct training. A similar analysis was conducted concerning the trainer manpower needed to conduct required AFS 328X4 training under the Current U&T scenario. It would appear that there is little or no impact on the ability of the field to conduct such training; sufficient personnel were available for this purpose (or sufficient personnel of the next high grade level were available to be substituted as OJT trainers).

5.1.2.2 AFS 328X4 Optimization Analysis - Given the almost limitless number of possible changes which might be studied, a TDS analyst or functional user might wish to take another approach to assessing the possible impact of specialty training changes. This approach could make use of the IOS optimization software. The analyst or user can specify an objective function or goal (such as minimization of OJT cost or total training costs, or maximization of the amount of available equipment, etc.), run the optimization program, and examine the effects on the specialty if the objective function is maximized or minimized. The analyst can ask "What if" questions; for example:

What is the impact on total training costs if we minimize initial resident course instruction?

What happens to specialty jobs (proficiency), if we maximize FTD training and minimize OJT?.

What is the impact on proficiency acquisition and training costs, if we have a 10% cut in new recruits entering training?

REPRESENTATIVE SITE: 1
Training Capacity: - Upper Bound: 18; Lower Bound: 12
Total Trainees Required: 30

Resource ID	Amount Avail.	Amount Required	Avail/Req Ratio	Max Trnees Supportable	Trainees Required	Trainees Unsupportable
18	5840.0	0.2	30917.65	826695.	26	0
27	1800.0	7.9	227.27	6782.	29	0
39	208.0	823.2	0.25	12.	30	18 <<<<<<<
68	1560.0	2.0	5902.30	111941.	30	0
91	520.0	1.9	277.42	7543.	27	0
104	5840.0	29.8	195.97	5864.	30	0
150	17520.0	61.6	284.49	8658.	30	0
160	52.0	77.1	0.67	16.	27	9 <<<<<<<
183	8760.0	0.7	13431.01	82007.	6	0

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Table 5.5 Example Representative Site Training Capacity Results: Current U&T Pattern (Adapted from AFS 328X4 Report, 15 Feb 88, Table 8.1).

Some potential optimization problems become visible during modeling runs of the specialty as training constraints are identified, or possible new models may be suggested by initial optimization runs. Other possible optimizations will be suggested by general Air Force trends, such as budget cuts or changing operational priorities. In some cases, these could be complex problems with multiple values to be optimized.

The approach taken in employing optimization algorithms to solve maximization or minimization problems in the TDS is to employ modular data bases and seek solutions at the lowest possible level. This isolates solutions to only the area of interest and has considerable efficiency in terms of saving computer time. Only the largest optimization problems, such as minimizing total specialty training costs, would require employment of the entire TDS data base. More limited problems can thus be dealt with by limited program runs.

As part of the exercise of the TDS software, we tested the optimization software with the AFS 328X4 data set. This section summarizes results of a single TDS optimization problem as an example of this capability.

The purpose of this optimization analysis was to determine the numbers of hours on task modules (TMs) in the FTD course J4AMF328X4-125, Carousel IVE, which will minimize total training costs, including OJT. This FTD course currently covers two TMs, 73 and 74, and provides training on these TMs in both the classroom and guided hands-on training settings. The analysis optimized hours for these two TMs in these two settings. Table 5.6 summarizes the overall cost results obtained by optimization as compared to the present (Current U&T Pattern) allocation.

Table 5.6

FTD J4AMF328X4-125 Optimization Results

	Current U&T Pattern (baseline)	Optimization Results
ABR course costs	$ 1,676,353	$ 1,676,353
FTD -125 costs	$ 73,092	$ 24,097
All advanced course costs	$ 1,047,943	$ 999,183
Total formal training costs	$ 2,724,296	$ 2,675,536
Total OJT costs	$ 5,096,500	$ 5,102,513
Total OJT hours	682,555	683,398

As may be seen, the overall costs associated with FTD -125 were reduced by about $49,000. OJT costs went up by about $6,000, so that the overall cost reduction was about $43,000.

Table 5.7 summarizes the hours on the selected TMs, both before and after optimization.

Table 5.7

Optimization Results

Task Module (TM)	Setting: Classroom Base-line	Setting: Classroom Optim-ization	Setting: Hands-on Base-line	Setting: Hands-on Optim-ization
73	50 hrs	1 hr	98 hrs	1 hr
74	24 hrs	1 hr	36 hrs	46 hrs

As may be seen, the optimization analysis suggests that TM 73 should be, in effect, eliminated from the FTD and that TM 74 should be covered only in the guided hands-on setting. The optimized FTD -125 had no impact on OJT capacity.

The baseline, the 328X4 current U&T pattern, violates several OJT nonlabor resource capacity constraints. The optimized alternative U&T pattern presented here did not violate any additional constraints.

The optimized version of FTD course -125 appears to offer significant cost reduction possibilities with little impact on OJT. The nature of the optimization program is such that it cannot take into account travel costs. The people taking a course, and travel costs associated with getting them to the course, are taken as fixed in the optimization run. In this situation, the best alternative might be to eliminate the course. This would save the travel costs associated with the course; the travel costs saved might more than make up for the additional OJT costs.

This example of Optimization is a very basic one, yet it demonstrates the capability of the TDS to employ this type of advanced technology to go beyond comparing predefined alternatives to actually formulate a new alternative U&T pattern (based on the outcomes of the optimization problem).

This type of technology is most appropriate where the policy issue (or question to be answered) is an issue which can be stated in terms of some value to be maximized or minimized.

5.1.3 AFS 811XX, Security and Law Enforcement Specialties

Basic data files for the Security and Law Enforcement specialties were reviewed and some preliminary runs made. A few minor errors were detected and corrected; one of these errors involved the omission of one entry point for the Military Working Dog course involving cross trainees from Law Enforcement after their first assignment (course 1025 was missing from all 811XX FRMJOB files). This omission involved only one half of one percent of LE first assignment personnel so that the impact of the error is relatively minor. It needed to be corrected, however, before further runs were made for these specialties.

With three specialties and six assignment periods, the AFS 811XX data files become very complex and difficult to quality control properly. Accurate tracking of data files and changes under alternative models is critical to successful data runs.

Final analysis data runs were completed for the Current U&T Pattern and six alternative U&T patterns. Perhaps the most interesting results are the comparisons of total training costs for these seven patterns (using the Current as a baseline to assess the changes), as shown in Table 5.8.

Table 5.8

Comparison of AFS 811XX Training Costs

U&T Pattern	Formal Course Training Costs	OJT Costs	Total AFS Training Costs	Percent Change
	(In Thousands of Dollars)			
Current U&T	24,295	14,987	39,282	Baseline
Alt. 1*	31,478	21,386	54,864	+ 39.7%
Alt. 2	24,814	15,492	40,306	+ 2.6%
Alt. 3	24,049	14,947	38,996	- 0.7%
Alt. 4	22,739	15,351	38,990	- 0.7%
Alt. 5**	24,052	14,987	39,039	- 0.6%
Alt. 6	22,493	13,833	36,326	- 7.5%

* Does not include transfer of ABGD training to Ft. Dix, NJ (Oct 87)

** Calculated as a 5% reduction of LE ABR attendance (1% of total formal school costs) with no reduction in OJT costs.

This type of comparative display permits a very concise evaluation of a set of TDS analyses and provides a very comprehensive perspective on the impact of several alternative proposals. In this case, the current AFS 811XX U&T pattern (as of the time of the TDS study in 1984-85) involves a total training cost of about $39 million per year, with $24 million of that total associated with formal training costs. Most of the cost consists of student and trainer manhours.

Alternative 1, which involves the greatest change, is a change whereby all AFS 811XX trainees would attend Air Base Ground Defense (ABGD) training prior to their first assignment. This alternative was an active proposal at the 1985 Training Planning Team (TPT) conference and was actually implemented as of 1 October 1987, when all new graduates have been sent to Ft. Dix, NJ, enroute to their initial assignments. The TDS analysis of this alternative suggests that this policy change results in a cost increase of about 39.7%, to almost $55 million per year (without considering the one-time costs of moving the course to Ft. Dix).

[Note: In a very real sense, what was Alternative 1 has become the new Current U&T Pattern. That is, it more accurately describes the present situation for AFS 811XX than does the "Current U&T Pattern" developed in the earlier TDS project. The other alternative U&T patterns would need to be reformulated to include the additional training which is now required (ABGD training and practice for everyone). For the purposes of the present project, such changes have not been made since the updating of AFS files and reanalysis of alternatives was not a formal project objective.]

Alternative 2 represents a proposal to merge AFSs 811X0 and 811X2 at the 7-skill level (rather than at the 9-skill level at present). This was modeled as a merged 7-level supervisor's course and free cross flow of assignments at the sixth assignment and beyond. This change increases total training costs by approximately $1 million per year; some of this increase involves the formal course (the new 7-skill level course is slightly longer than the present separate courses). The remainder of the increase is associated with increased OJT resulting for members of either specialty cross flowing to assignments in the other area.

Alternatives 3 - 5 have very little impact on total training costs. Alternative 3 involves splitting the Military Working Dog specialty (presently AFS 811X2A) into two specialties, since some jobs are more associated with security flight operations (AFS 811X0). This change would create more complicated job flows but, as can be seen in Table 3.8, has very little impact on training costs. Alternatives 4 and 5 would transfer some administrative jobs to other specialties or have those who have Law Enforcement training by-pass the ABR; these proposals change some job and training flows but have essentially no impact on training costs.

Alternative 6 involves contracting some jobs out, thus reducing the total military manpower of the specialty. Some law enforcement and guard jobs are already contracted at some (but not all) Air Force Systems Command (AFSC) and Air Force Logistic Command (AFLC) bases. Extending such contracting to all bases in the noncombatant commands (including AFLC, AFSC, and Air Training Command) would save about $3 million dollars per year in AFS 811XX training costs. It is not known, however, how much training civilian guards on Air Force procedures would cost.

This type of summary comparison provides a concise and understandable picture of the impacts of the proposals on total AFS training costs. It is a very useful display which was requested by potential TDS users at the final TDS Progress Review (September 1988). This type of display is created manually by synthesizing and condensing information from a series of TDS reports.

5.1.4 AFS 305X4, Electronic Computer and Switching Systems Specialty

Basic data runs for the Electronic Computer and Switching Systems specialty were completed with no major errors detected. AFS 305X4 involves an extremely complex data set since there are multiple 3-skill level subspecialties each with its own basic resident course or FTD program. These subspecialties merge at the 5-skill level into a common specialty, although the subspecialty jobs continue to exist through the supervisory level. Complete runs for this specialty resulted in cost data comparisons shown in Table 5.9 below:

Table 5.9

Comparison of AFS 305X4 Training Costs *

U&T Pattern	Formal Course Training Costs	OJT Costs	Total AFS Trng Costs	Percent Change
	(In Thousands of Dollars)			
Current U&T	2,788	4,926	7,714	Baseline
Alt. 1	2,540	5,011	7,551	- 2.1%
Alt. 2	2,900	5,112	8,012	+ 3.9%
Alt. 3	5,424	4,065	9,489	+ 23.0%
Alt. 4	3,214	4,802	8,016	+ 3.9%
Alt. 5	2,569	5,248	7,817	+ 1.3%
Alt. 6**	-	-	-	-

* Data as of July 1988
** Involves merger with other AFSs (for which there are no TDS data)

Note that in the current U&T pattern for AFS 305X4 (as of 1988 when the study was finalized) total training costs over seven and a half million dollars per year, with the majority of that cost ($4.9 million) involving OJT costs. AFS 305X4 is an extremely diverse specialty, with multiple 3-skill level shredouts and multiple ABR courses. [Note: subsequent to the TDS data collection effort, the specialty was changed with Autovon switching systems jobs being moving to another maintenance specialty, and several shredouts deleted].

Alternative 1 was a proposal to have a common ABR course focusing on electronics principles with most training deferred until the first job. Under this proposal, formal course training costs are reduced somewhat ($248,000) but OJT costs rise only slightly ($85,000), for an overall savings of 2.1%. This result suggests that the present ABRs have little specific equipment training and are already focused on fundamentals.

Alternative 2 was proposed by Airborne Warning and Control Systems (AWACS) SMEs to use only more experienced cross-trainees in AWACS jobs, thus avoiding extensive AWACS training of new recruits. Such a change would actually increase overall training costs by some $298,000 per year, with that cost split between formal courses and OJT. While this alternative was preferred by AWACS managers, it was not popular among other senior personnel of the specialty.

Alternative 3 was very similar to Alternative 1 except that training would be focused in FTDs rather than OJT. This results in extensive cost growth in formal courses ($2,636,000) with only a moderate savings in OJT ($861,000). While this is a desirable option (since it reduces field OJT demands), it is the most expensive alternative considered.

Other alternatives (4 & 5) involved other training configurations and had only moderate cost implications; SMEs did not consider either of these alternatives very realistic as possible changes.

Alternative 6 involved splitting the AFS with some jobs moving to another AFS (not studied in TDS R&D). Without data from the other AFS, this option could not be evaluated. This restructuring was the option which the Air Force actually decided to do; the change moved Autovon Switching maintenance jobs into another electronics specialty and the remaining jobs were redesignated.

5.2 Troubleshoot, Enhance and Refine TDS Software

As noted earlier, TDS software and data files were reviewed to detect errors or anomalies which might suggest software problems. In addition, new versions of several TDS programs were developed, as well as several new programs which are ready for implementation on the AFHRL UNISYS. We have also defined some new and updated data files. The purpose of this section is to summarize those updates.

5.2.1 Updated and New Programs:

UTPSIM - Two situations were identified in which errors in input data files could cause erratic program behavior. In both cases, the impact on program output was very small, so the program was not rerun. The program has been updated to detect these circumstances. In one case, the program can make a correction. In the other case, the program prints an error message. This latter case arises when an entry (e.g., job or training course) is missing from the FRMJOB file (LN12-nnn09a.). The problem was that course 25 (1025) was missing from all 811XX FRMJOB files. This problem should be corrected in all such files on the UNISYS (e.g., LN12-81109., LN12-811093.). UTPSIM has been updated on the UNISYS.

TRNPRF - This program has been updated to correct a small error which caused OJT counts to be incremented occasionally when no OJT hours were being given and to output a new data file which is used in the linear programming capacity analysis. The impact of the error on program output was small; previous runs do not need to be rerun. The new data file, described below, contains OJT hours given on each TM to each simulated airman in each job; this file may be thought of as an extension to the entity history file ·: will be called the ENTOJT file or entity OJT hours file. The TRNPRF has been updated on the UNISYS; however, there is still a need to update the ECL generation facility for the new data file.

RCSCRO - This program estimates hours of nonlabor resources required for OJT. It corrects a small problem with the version of this program on the VAX version of the program. A complete new version of this program has been loaded to the UNISYS.

RCSCRAT - This program does ratio capacity analysis for nonlabor resources in OJT. It has been updated to improve the output report formats and to provide a new data file needed for linear programming capacity analysis. Three data files produced by the old version of this program are obsolete. A new version of the program has been loaded to the UNISYS.

RCSCRCT - In general, training resource quantities are estimated by applying linear regression equations to training hours output from TRNPRF. Such an equation is needed for each TM by resource (student labor hour, instructor preparation labor hours, instructor delivery labor hours, non labor resources) by setting combination. For some such combinations, no equation is available (for lack of data estimates). The old versions of all RCS resource requirement estimation programs estimated zero resource hours when no regression equation was available. In the case of student labor hours, it makes more sense to use the TRNPRF training hours than a zero value for TM-by-setting combinations with no regression equations. The new version of RCSCRCT implements this approach for student labor hours in non-OJT settings. A new version of the program is now on the UNISYS.

RCSCROCT - This program implements the improvement described above for RCSCRCT for student OJT labor hours. A new version of the program has been loaded to the UNISYS.

RCSCOSCS - This is a new program which estimates cost per student week of training (in contrast to the existing cost program, which estimates annual costs). A new version of the program has been loaded to the UNISYS.

RCSMCCOS - This is a new program which estimates annual OJT costs for the major commands. This program allocates OJT costs (currently built up by job and representative site) to the major commands. It requires a new data file for each AFS which contains percentages of airmen at each representative site that are in each major command. These files for the four AFSs, named MAJPCT.nnn, have been created and loaded to the UNISYS.

RCSCTRAO - This program applies the ratio capacity analysis method for instructors in OJT. It takes into account instructor grade level, based on average grade level of trainee, and instructor substitutability (e.g., higher-grade instructors can be used in place or required lower grades, but the reverse is probably not true). A new version of the program has been loaded to the UNISYS.

LINCAP - This program applies the linear programming capacity analysis method for nonlabor resources in OJT. The program requires three new input files. These are: (a) a file output from the ratio capacity program (RCSCRAT) which specified which representative sites and resources are to be analyzed, (b) a file which specified which TMs are to be included, and (c) a file, output from TRNPRF, which contains data on OJT hours by TM for each simulated airman. In addition, the RCS run parameter file (LN12-nnnR01a) contains some additional parameters. The source code for this program has been loaded to the UNISYS: LINCAP (main program); CLOX, CLOX0001, CLOX0002, and ZSXPHD (sub- routines called by LINCAP), and LINPACK1 (subroutines called by ZSXPHD). This program will not be fully implemented on the UNISYS until new program documentation has been written. It also requires the updated versions of TRNPRF and RCSCRAT.

5.2.2 Updated and New Data Files:

Entity OJT Hours File - This new file is output from the updated version of TRNPRF. It contains OJT hours by TM for each simulated airman and job in the simulation. This file is used for linear programming capacity analysis and may eventually be used by all RCS programs.

MAJCOM Percentage File - This file contains MAJCOM percentages for representative sites and is used to estimate MAJCOM OJT costs.

Ratio Capacity Short Resources File - This file identifies resources that are short at representative sites. It is output from the nonlabor resource OJT ratio capacity analysis program and input to the linear programming capacity analysis program.

Ratio Capacity Short Resource TM File - This file lists TMs which require specified resources. It is output from the LPCTTM file, based on an input ratio capacity short resource file. This file is input to the linear programming capacity analysis program.

RCS Run Parameter File (LN12-nnnR01a) - This file contains several additional parameters that are used by the linear programming capacity analysis program. The file need not be updated for use by other RCS programs except the major command costing program.

5.2.3 New Procedure for Estimating FTD Travel Costs

In the original version of the TDS, each FTD course was assumed to be held at the primary base designated to provide such training in AFR 50-5. Travel costs were estimated using the assumption that personnel in other units traveled to the primary FTD location for training. To enhance and refine the operation of the TDS, the capability to estimate travel costs when an FTD course is held at more than one base (as is the case for many FTD courses) has been developed. The procedure operates as follows.

For each base where airmen who need to take a particular FTD course are stationed, the travel cost between that base and each of the bases where the FTD course is being offered (hereafter referred to as the FTD base is computed. The FTD base with the lowest computed travel cost is then selected and the simulated airmen are assigned to that FTD location. When the procedure is completed for all bases with airmen who need to take the FTD course, the FTD bases are ordered according to the number of airmen assigned to them. If the FTD base with the fewest number of airmen assigned to take the FTD has at least the minimum number of airmen required to hold a course, then the procedure is complete. The "minimum number" can be specified by the analyst (Currently, the number "2" is used as a default value). However, if this criterion is not satisfied, the FTD base with the fewest number of airmen assigned to it is eliminated (i.e., the FTD course is assumed not to be taught there) and those airmen are reassigned to the next least expensive FTD base. This procedure continues until all FTD bases have at least the minimum number of airmen required to hold a course.

5.3 Discussion of Constrained TDY-TO-SCHOOL Resources

In earlier sections of this report, some preliminary discussion of the possible reduction of 25 percent in TDY-to-school funds was included within the analysis of AFSs 423X1 and 328X4. As noted in those sections, the initial analyses were incomplete; they lacked a review of the impact on unit OJT capacity (pending having revised capacity software operational). Until the OJT capacity analyses revisions were operational, any extended discussion of the impact of the proposed reduction in TDY funds was not feasible. A short review of the capacity calculations is warranted.

The Training Capacity Component of the RCS systematically compares the estimated resource availabilities for the representative sites of an AFS to the total amounts of resources required at those sites to accommodate the specific volumes of training in particular training states that are designated for those sites within the U&T patterns developed in the FUS. This comparison first involves computing the ratio between the total amount of each resource that is available for the provision of training at each site and the total amount of the resource that is actually needed to provide all of the training designated for the site within a particular U&T pattern. For provision of the designated amount of training to be unequivocally feasible, the calculated ratios for all required resources must uniformly be greater than or equal to 1.0.

Conversely, if a ratio less than 1.0 is calculated for any required resource, it is infeasible to conduct all designated training at the site. Moreover, if ratios less than 1.0 are calculated for two or more required resources, the cumulative effect of the concurrent shortages of those resources on the capacity of the site to provide the required training will, in general, depend upon the feasibility of concentrating those resource shortage effects on a restricted group of trainees.

Mathematical programming provides a means for evaluating the feasibility of allocating training resources in such a way that the trainees to whom training is not provided are so concentrated. This involves calculating the number of people who should be trained in each training state at each site so that the total number of people who receive their designated training is maximized and, at the same time, certain constraining conditions are satisfied. The applicable constraints include, most notably, that no training in excess of the amount designated in the U&T pattern is conducted in any training state, and that no more than the total amount of each resource available for the provision of training is used at any site.

The results obtained by applying this method of training capacity estimation to evaluate the training capacity of representative site 1 for AFS 328X4 for both the current U&T pattern and the reduced TDY-to-School funding scenario are summarized in Table 5.10. Results are presented jointly to facilitate a comparative analysis of these two U&T patterns to show how training constraints are identified and quantified. These results were derived within the context of a linear programming formulation of the estimation method, as discussed above.

Section A indicates the total number of trainees, 3.41 per year on average, for whom the provision of training at the site has been designated by the FUS. Next, Section B compares the estimated amounts of individual resources available at the site and the estimated amounts of those resources required for the provision of all training designated for the site by the FUS. The first and second columns of Section B indicate the specific U&T patterns and resources to which the estimates relate. The third and fourth columns contain the estimates derived in the RCS for the amounts of those resources available and required, for providing the training required for the representative site within the U&T pattern. The fifth column for each U&T pattern presents the ratios of the amounts available to the amounts required for individual resources. A ratio greater than or equal to 1.0 indicates that the amount of the resource available at the site is sufficient to provide the total amount of training needed to sustain the U&T pattern. Conversely, a ratio less than 1.0 means that there is a shortage of the resource at the site.

Section C. reports the estimate of training capacity derived for each U&T pattern by means of linear programming. These estimates indicate the numbers of trainees, 2.89 and 2.88 per year on average, to whom all designated training for the two U&T patterns can be provided with the amounts of resources available at the site. Thus, in combination, the estimates presented in Sections A and C state that for units characterized by this representative site, 0.52 and 0.53 trainees per year, on average, will not receive some portion of the training designated for them within these two U&T pattern scenarios. Thus, we can see that the Reduced TDY-to- School change has had very little (essentially no) impact on OJT capacity.

The linear programming analysis also identifies the specific resource that imposes the most restrictive limitation on the capacity of the representative site to accomplish all of the training designated within the U&T pattern. Accordingly, for the two resources for which the total amounts available are insufficient for providing all of the training designated for the representative site, the estimates reported in Section D of Table 5.10 indicate that for both U&T patterns, the total amount of resource 39 (aircraft) that is available for providing training is equal to the total amount required for providing the maximum achievable quantity of training, whereas the total amount available of resource 160 (weapons release control system analyzer) exceeds the amount required for providing the maximum achievable quantity of training by 17.1 units for the current U&T and 12.1 units for the reduced TDY-to-School U&T alternative. Thus, in this situation, resource 39 imposes the most restrictive constraint on the training capacity of the representative site.

Table 5.10

Estimated OJT Capacities for Typical Units
Characterized by Representative Site 1

A. Total trainees requiring training: 3.41
B. Resource Constraints limiting the provision of required training:

U&T Pattern	Resource	Amount Available	Amount Required	Ratio of Availability to Requirements
Current U&T	39	208.0	823.2	0.25
	160	52.0	77.1	0.67
	188	1506.0	77.0	20.27
Reduced TDY-to-School Funding	39	208.0	829.8	0.25
	160	52.0	80.8	0.64
	188	1560/0	77.7	20.09

C. Linear Programming Estimates of Training Capacity:

Current U&T Pattern	2.89
Reduced TDY-to-School U&T Pattern	2.88

D. Resource Constraints Limiting Maximum Amount of Training Achievable:

U&T Pattern	Resource	Amount Available	Amount Required
Current U&T	39	208.0	208.0
	160	52.0	34.9
Reduced TDY	39	208.0	208.0
	160	52.0	39.9

This type of information, considered site by site, must be evaluated along with the formal training and OJT costs in any comparison of two or more alternative U&T models. All of these data are available for managers use in assessing the possible consequences of changing AFS training programs, jobs, and utilization policies.

5.4 Summary and Recommendations

An extensive exercising of the TDS software has been completed for the four TDS R&D specialties including OJT capacity analyses. Results of these exercises indicate the system is operating well and produces detailed and very useful reports and data.

In addition to the work originally planned, training cost reports for new policy issues involving the two maintenance specialties were given priority, at the request of AFHRL/IDET, to assure the availability of information for briefing the MATAG in mid-May 1989. Results for a reduced TDY-to-School U&T pattern as well as the current U&T for the two maintenance specialties were carefully checked and appear reasonable. A new U&T pattern involving a 25% reduction in ABR flow was developed to meet an additional AFHRL/IDET request and cost reports for the two specialties completed. These data were delivered to AFHRL on 12 May 1989, and were used in briefing the MATAG. This exercise demonstrated a relatively quick response capability for answering queries from functional managers concerning AFSs studied in the TDS R&D, and thus was an extremely valuable addition to the work planned for the present project.

TDS software troubleshooting resulted in a number of minor changes to FUS and RCS programs; most changes have little if any impact on AFS data files or reports. Some programs were revised to improve efficiency or correct minor problems; some additional programs were written to provide internal quality control checks and greater flexibility.

RCS software has been substantially upgraded and most of the revised programs are now available on the UNISYS at AFHRL, although not all have yet been completely tested and debugged. These major upgrades include improvements in the OJT training capacity program, new capability to summarize data by MAJCOM, and a substantial revision of FTD travel costing procedures. The latter program is operational and has been tested on the CONSAD VAX but has not yet been tested on the UNISYS; it must also undergo further quality control evaluation by MDC and Metrica analysts and programmers. We recommend such testing and quality control be undertaken in the near future.

Optimization software was tested in a limited optimization problem on one FTD of AFS 328X4 training programs. This test indicated the system is now operational (on the MDC VAX) and demonstrated the approach needed to utilize this system capability. Additional tests are needed before the optimization software is made fully operational on the UNISYS. We recommend such testing be include in any future TDS work.

Overall, the TDS Software Exercise was a very successful undertaking. Some problems with data files and programs were discovered and corrected. In addition, such problems led to the design and implementation of system improvements. However, due to additional system exercises (Reduced TDY-to-School and reduced ABR scenarios) and other activities (TDS training for AFHRL analysts), some improvements in product formats and subsystem programs could not be completed within the framework of the present project. We recommend that these improvements be included in any future TDS task work or within the context of future TDS R&D projects.

6.0 SENSITIVITY ANALYSIS

The TDS Integration and Optimization Subsystem (IOS) modeling soft ware was subjected to an extensive series of sensitivity analyses. These sensitivity analyses examined the effects of seven input variable classes on three output variables. The analyses were done so that main effects of the seven input variable classes could be assessed, as well and two- and three-way interactions of the input variable classes. This sensitivity analysis extends the sensitivity analysis conducted earlier under the TDS proof-of-concept contract. The earlier work involved sensitivity analyses for the 328X4, Radar and Inertial Navigation Systems specialty. The present work involved similar analyses with the 423X1, Aircraft Environmental Systems specialty, the 305X4, Computer and Electronic Switching Systems specialty, and the 811XX, Security Police specialties.

The purpose of these sensitivity analyses was to investigate the effects of variations in input parameters on the operation of program objective functions. More specifically, the sensitivity analyses had three objectives: a) to identify and rank input variables which affect objective program functions, b) to identify and rank any two- and three-way interactions between and among input variables which affect objective program functions with the main effects of singular variables, and c) to fully evaluate the effects of the entire range of the input variables on each objective function.

6.1 Methods

In these sensitivity analyses, seven classes of input variable were manipulated, including both Field Utilization Subsystem (FUS) utilization and training (U&T) pattern modeling inputs and Resource/Cost Subsystem (RCS) resource requirements and cost modeling inputs. Current U&T pattern values were used as a baseline. Inputs were systematically increased and decreased for each input variable class. Effects of these changes and interactions among these changes were determined on total formal training costs, total on-the-job (OJT) training costs, and total training costs.

The overall TDS U&T pattern and cost modeling functions are embodied in the following computer programs:

1. UTPSIM: U&T pattern simulation
2. TRNPRF: OJT estimation
3. RCSCRCT: Student formal training labor hour resource requirement estimation
4. RCSCROCT: Student OJT labor hour resource requirement estimation
5. RCSCRCI: Instructor formal training labor hour resource requirement estimation
6. RCSCROCI: Instructor OJT labor hour resource requirement estimation
7. RCSCOSTS: Formal training and OJT cost estimation

Several other TDS programs are concerning with training capacity estimation, optimization, and utility functions. The sensitivity analyses reported here focused on training cost estimation and on the programs listed above. These programs and their various inputs and outputs are documented in the TDS User Manual and the TDS Programmers Guide developed for this project (see Preface).

Seven input variable classes were manipulated. Three sets of values were used for each class: current U&T pattern values and two other sets. These input variable classes and their values are described below:

Random number seed - The U&T pattern simulation (UTPSIM), which estimates job and training flows, is a monte carlo simulation. It uses a stream of pseudorandom numbers generated by the computer determine the direction taken by each simulated entity at each choice point. The random number stream used for a computer run is determined by a seed which is input. Three different random number streams were used for the 328X4 and 423X1 specialties, determined by three seed values. For the 305X4 and 811XX specialties, two random number streams were used, determined by two seed values.

Job transition probabilities - A set of transition probabilities input to the UTPSIM program are used to determine the job, between-job training, or leave state that simulated airmen go to from each job or between-job training. The set of transition probabilities from a particular job must sum to 100%. In addition to current U&T pattern values, a set of values was created by increasing large probabilities (greater than 20%) by 10% (e.g., multiplying them by 1.1) and decreasing small probabilities by 10% (e.g., multiplying them by .9). Similarly, a third set of transition probabilities was created from the current U&T pattern values by decreasing large probabilities by 10% and increasing small values by 10%.

Job-driven training transition probabilities - Job-driven training transition probabilities are used by the UTPSIM program to assign simulated airmen to training courses taken while in jobs (e.g., field training detachment courses). Since an airman can possibly take several job-driven training courses while in particular job, these probabilities need not sum to exactly 100%. Modified sets of these probabilities were obtained by increasing all current U&T pattern values by 10% (e.g., multiplying by 1.1) and by decreasing all current U&T pattern values by 10 % (e.g., multiplying by .9). In U&T pattern models for the 811XX specialties, most training courses were treated as job and time driven rather than job driven. Thus, for the 811XX specialty, job and time driven training transition probabilities were modified instead of job-driven training transition probabilities, using the procedure described here.

Allocation curve parameters - Allocation curves, in the TDS model, define the relationships between training hours and proficiency for each task module (TM) and training setting. These curves are modeled by second order polynomial equations; each TM-setting combination has two parameters (the additive constant is always zero). The allocation curve parameters are used by the TRNPRF program to estimation OJT hours needed to achieve full proficiency. Modified sets of these parameters were obtained by increasing all current U&T pattern values by 10% and by decreasing all current U&T pattern values by 10%.

Training TM hours - For each formal training course, hours devoted to each TM in each training setting are input to the TRNPRF program. These data are used to account for proficiency obtained by formal training in determining OJT quantities. Modified sets of these parameters were obtained by increasing all current U&T pattern values by 10% and by decreasing all current U&T pattern values by 10%.

Student resource requirement model parameters - For RCS purposes, student labor hours (instruction and preparation) required for training programs are estimated (programs RCSCRCT and RCSCROCT). This is done using a two-parameter linear model for each TM and training setting. Ses if modified parameters were obtained by increasing all current U&T pattern values by 10% and by decreasing all current U&T pattern values by 10%.

Instructor resource requirement model parameters - For RCS purposes, instructor labor hours (instruction, preparation, and administration) required for training programs are estimated (programs RCSCRCI and RCSCROCI). This is done using a two-parameter linear model for each TM and training setting. Modified sets of these parameters were obtained by increasing all current U&T pattern values by 10% and by decreasing all current U&T pattern values by 10%.

These seven input variable classes with three sets of input values for each class define a 3X3X3X3X3X3X3 factorial experimental design (2X3X3X3X3X3X3 for 305X4 and 811XX). One complete replication of this design would require 2187 TDS modeling runs. Since it was not necessary to assess interactions beyond the second order, it was not necessary to make all of these runs. In fact, 1256 modeling runs were made for 328X4, 1215 runs were made for 423X1, and 810 runs were made for 305X4 (fewer runs were needed for 305X4 and 811XX because only two levels were studied for the random number stream). These runs permitted all interactions through the second order to be assessed, with some residual to evaluate the overall impact of higher order interactions. For each selected cell in the design, a complete TDS cost modeling run was made. The total formal training cost, total OJT cost, and total training cost (sum of formal training cost and OJT cost) was retained for analysis.

6.2 Results

6.2.1 AFS 328X4

For completeness and comparative purposes, results for the 328X4 specialty are summarized here. Table 6.1 presents proportions of variance attributable all main effects and to those higher-order effects which accounted for at least 1% of the total variance.

Detailed ANOVA results for AFS 328X4 are presented in CDRL CLIN0001:33 from the proof-of-concept TDS contract. Table 6.2 presents within-group means on each outcome variable for levels associated with all main effects and with the job transition probability by job-driven training transition probability interaction effect.

The AFS 328X4 results contained in Tables 6.1 and 6.2 were summarized from the previous sensitivity analysis report. Some additional analyses were done for the present project. These results provide a better basis for evaluating the actual magnitudes of the impacts on training costs associated with the independent variables in the sensitivity analysis. Consider, first, the random number stream or seed factor. In the context of the sensitivity study design, this is a random effect.

The actual seed values used were sampled from a population of possible values; The training cost effect magnitude of this factor can be measured by the cost variance associated with the effect. As shown in Table 6.1, the random number seed effect accounted for very little of the overall cost variance. Unbiased estimates of the training cost standard deviation associated with the random number seed factor, for formal training, 4320; for OJT, 36523, and for total costs, 40452. Under the usual assumptions, one would expect costs to vary by as much as plus or minus these amounts about 68% of the time due to changes in the random number stream used.

Effect	Total Formal Training Cost R^2	Total OJT Cost R^2	Total Training Cost R^2
Random number seed (A)			
Job transition probabilities (B)		.02	.02
Training transition probabilities (C)	.10	.02	.05
Allocation curve parameters (D)		.35	.20
Training TM hours (E)	.38	.02	.02
Student resource requirement parameters (F)	.38	.45	.56
Instructor resource require parameters (G)		.04	.03
BC	.10	.06	.10

Note: When no R^2 value is given, the value is less than .01

Table 6.1 AFS 328X4 ANOVA Summary

	-10%	Normal	+10%
Random number seed (A)			
Formal training	2744450	2754270	2747990
OJT	5095300	5136830	5055100
Total training	2744450	7891100	7803090
Job transition probabilities (B)			
Formal training	2745190	2766720	2732230
OJT	5164310	5133660	4999520
Total training	790951	7900390	7731760
Job-driven training transition probabilities (C)			
Formal training	2630000	2742220	2860270
OJT	4974710	5136260	5124470
Total training	7604720	7878480	7984740
Allocation curve parameters (D)			
Formal training	2748920	2750050	2748450
OJT	5428160	5116230	4753010
Total training	8176770	7866290	7501470
Training TM hours (E)			
Formal training	2563140	2750000	2931970
OJT	5180030	5110050	5002760
Total training	7743170	7860060	7934740
Student resource requirement parameters (F)			
Formal training	2552120	2758210	2936940
OJT	4696180	5110230	5481680
Total training	7248300	7868840	8418630
Instructor resource requirement parameters (G)			
Formal training	2724590	2759430	2763780
OJT	4974650	5109810	5204440
Total training	7699240	7869250	7968230
B by C: (columns reflect levels of C)			
B1 (-10%):			
Formal training	2342730	2802820	2111160
OJT	4648270	5324560	5290760
Total training	6991010	8127380	8201920
B2 (Normal)			
Formal training	2744910	2744890	2849220
OJT	5137760	5143880	5103320
Total training	7882670	7888780	7952540
B3 (+10%)			
Formal training	2706360	2705880	2808340
OJT	5006000	5024020	4941280
Total training	7712370	7729910	7749620

Table 6.2 AFS 328X4 Within-level Training Cost Means

The remaining independent variables in the sensitivity analysis are fixed effects. For these effects, the regression parameter associated with the linear contrast for an effect estimates the amount of cost change associated with a 10% change in the factor value (since levels of the factors were produced by changing the actual values by 10%, as described above). These regression parameters are presented in Table 6.3.

	Formal Training	On-the-job Training	Total Training
Job transition probabilities (B)	- 3717	- 79068	- 82780
Job-driven training transition probabilities (C)	113454	69966	183420
Allocation curve parameters (D)	238	- 338168	- 338405
Training TM hours (E)	183659	- 90019	93640
Student resource requirement parameters (F)	192072	393199	585270
Instructor resource parameters (G)	19599	114897	134496

Table 6.3 AFS 328X4 Main Effect Linear Regression Parameters

AFS 423X1 Results

Table 6.4 summarizes the proportions of variance accounted for by all main effects and other effects which account for at least 1% of the cost.

Effect	Total Formal Training Cost R^2	Total OJT Cost R^2	Total Training Cost R^2
Random number seed (A)			
Job transition probabilities (B)	.01	.01	.02
Training transition probabilities (C)	.38	.01	.02
Allocation curve parameters (D)		.03	.03
Training TM hours (E)	.24	.08	
Student resource parameters (F)	.29	.53	.64
Instructor resource parameters (G)	.02	.03	.03
AB	.02	.03	.03

Note: When no R^2 value is given, the value is less than .01

Table 6.4 AFS 423X1 ANOVA Summary

Table 6.5 presents training cost within-cell means for all main effects and for the random number seed by job transition probability interaction. For all three training costs, unbiased estimates of variance associated with the random number seed factor were negative. Maximum likelihood estimates of these variances were zero. While these variances are probably not, in fact, zero, they are very low. Table 6.6 presents regression parameters associated with linear contrasts for the fixed effects in the sensitivity analysis.

	-10%	Normal	+10%
Random number seed (A)			
Formal training	2089237	2109533	2097944
OJT	5472783	5493664	5465808
Total training	7562020	7603196	7563752
Job transition probabilities (B)			
Formal training	2120279	2098272	2078163
OJT	5514284	5493221	5424750
Total training	7634563	7591493	7502913
Job-driven training transition probabilities (C)			
Formal training	1988011	2098451	2210251
OJT	5513340	5483408	5435508
Total training	7501351	7581859	7645759
Allocation curve parameters (D)			
Formal training	2098949	2098726	2098949
OJT	5534315	5546870	5385796
Total training	7633264	7645596	7484745
Training TM hours (E)			
Formal training	2021537	2098726	2176360
OJT	5568818	5546870	5351293
Total training	7590356	7645597	7527654
Student resource requirement parameters (F)			
Formal training	2002333	2098990	2195390
OJT	5146145	5477470	5808640
Total training	7148477	7576461	8004031
Instructor resource requirement parameters (G)			
Formal training	2086933	2098911	2110868
OJT	5260834	5477498	5693922
Total training	7347768	7576410	7804790
A by B: (columns reflect levels of C)			
A1 (seed 1):			
Formal training	2101866	2128074	2037770
OJT	5583843	5528247	5386261
Total training	7685709	7656321	7424031
A2 (seed 2)			
Formal training	2140347	2093105	2095147
OJT	5630088	5481112	5369790
Total training	7770434	7574217	7464938
A3 (seed 3)			
Formal training	2118624	2073636	2101572
OJT	5408919	5470306	5518199
Total training	7527543	7543941	7619772

Table 6.5 AFS 423X1 Within-level Training Cost Means

	Formal Training	On-the-job Training	Total Training
Job transition probabilities (B)	- 21058	- 44767	- 65825
Job-driven training transition probabilities (C)	111120	- 38916	72204
Allocation curve parameters (D)	0	- 74260	- 74260
Training TM hours (E)	77412	-108763	- 31351
Student resource requirement parameters (F)	96529	331248	427777
Instructor resource requirement parameters (G)	11967	216544	228514

Table 6.6 **AFS 423X1 Main Effect Linear Regression Parameters**

AFS 305X4 Results

Table 6.7 summarizes the proportions of variance accounted for by all main effects and other effects which accounted for at least 1% of the cost variance. Table 6.8 presents training cost within-cell means for all main effects.

Effect	Total Formal Training Cost R^2	Total OJT Cost R^2	Total Training Cost R^2
Job transition probabilities (B)	.03	.22	.16
Training transition probabilities (C)	.13		.03
Allocation curve parameters (D)		.15	.06
Training TM hours (E)	.50		.11
Student resource requirement parameters (F)	.29	.43	.51
Instructor resource requirement parameters (G)		.12	.07

Note: When no R^2 value is given, the value is less than .01

Table 6.7 **AFS 305X4 ANOVA Summary**

Unbiased estimates of the training cost standard deviation associated with the random number seed factor, for formal training, 8662; for OJT, 6678, and for total costs, the estimate was negative. Under the usual assumptions, one would expect costs to vary by as much as plus or minus these amounts about 68% of the time due to changes in the random number stream used.

	-10%	Normal	+10%
Random number seed (A)			
Formal training	3081153	3093470	
OJT	4920877	4811326	
Total training	7902031	7904603	
Job transition probabilities (B)			
Formal training	3158842	3078248	3024845
OJT	5020032	4833949	4594034
Total training	8178874	7912197	7618879
Job-driven training transition probabilities (C)			
Formal training	2950852	3087440	3223644
OJT	4836446	4815929	4795640
Total training	7787299	7903369	8019284
Allocation curve parameters (D)			
Formal training	3087328	3087247	3087328
OJT	4645067	4876915	4956488
Total training	7732395	7964161	8043817
Training TM hours (E)			
Formal training	2850498	3087247	3324159
OJT	4828844	4876915	4772711
Total training	7679342	7964162	8096869
Student resource requirement parameters (F)			
Formal training	2880975	3087371	3293590
OJT	4513049	4816016	5118950
Total training	7679343	7964162	8412540
Instructor resource requirement parameters (G)			
Formal training	3064247	3087314	3110375
OJT	4654502	4816150	4977363
Total training	7718749	7903464	8087738

Table 6.8 305X4 Within-level Training Cost Means

Table 6.9 presents regression parameters associated with linear contrasts for the fixed effects in the sensitivity analysis.

	Formal Training	On-the-job Training	Total Training
Job transition probabilities (B)	-66999	-212999	-279997
Job-driven training transition probabilities (C)	136396	- 20403	115992
Allocation curve parameters (D)	0	155711	155711
Training TM hours (E)	236830	- 28067	208763
Student resource requirement parameters (F)	206308	302950	509258
Instructor resource requirement parameters (G)	23064	161430	184494

Table 6.9 **AFS 305X4 Main Effect Linear Regression Parameters**

6.3 Summary and Recommendations

In general, the results for AFS 423X1 and 305X4 specialties replicate the sensitivity analysis findings for AFS 328X4. First, random number streams have very little impact on the bottom line training cost estimates.

In only one case did an effect involving the random number stream factor accounted for as much as 1% of the cost variance. TDS results are generally stable over different random number streams. Large differences between TDS analyses for different U&T patterns can be attributed to real differences in the U&T patterns, rather than simply to random variation due to different random number sequences. This is a very important finding--that TDS model results are not sensitive to particular random number sets used.

Another nonsignificant result of note is that for interactions. Of the 168 two- and three-way interactions for the three specialties, only two accounted for greater than 1% of training cost variance. The residual beyond the main effects and two- and three-way interactions was also less than 1%, showing that no higher-order interactions are important. Studying high-order interactions in sensitivity analyses such as the present one requires much effort. This is because many model runs are needed. However, if only main effects and low-order interactions are to be studied, many fewer model runs are needed. This permits such sensitivity analyses to be done with much less effort and permits many more input variables to be studied. It also permits simple estimation of impacts on costs for other changes in the independent variables studied here. We recommend that future TDS sensitivity analyses focus on main effects and perhaps on two-way interactions, rather than on higher-order interactions.

For formal training, the same variables were most important for all three specialties. These key variables are the training TM hours and the student resource requirement model parameters. Our previous experience with economic analysis of formal training suggests that student labor hours are the major cost contributor to classroom training. In the TDS model, student labor hours are function of the training TM hours as modified by the student resource requirement model.

For OJT, the results were less consistent across the specialties. In all specialties, the most important factor were the student resource requirement model parameters. In AFS 328X4, the allocation curve parameters were also important. In AFS 423X1, the training TM hours were important for OJT costs as well as for formal training costs. In AFS 305X4 the job transition probabilities were important, while the allocation curve parameters and the instructor resource requirement model parameters were of smaller, but practically significant, importance.

For total training costs, the results were moderately consistent across specialties; student resource requirement model parameters were the dominant factor. For two of the specialties, the training TM hours were important. For the third specialty, allocation curve parameters were important. Overall, it is clear that the TDS cost model is very sensitive to the student resource requirement model parameters. Given these results, we recommend that emphasis in future work be placed on testing improved methods for estimating these parameters.

The present sensitivity analysis looked at seven of the most important TDS input variable classes. The TDS model has many other input variables. We recommend that these additional variables be examined in future sensitivity analyses. These future studies can be streamlined by focusing only on main effects.

7. TRAINING DECISIONS TECHNOLOGY POTENTIAL APPLICATIONS

The Training Decisions technologies developed during the TDS R&D project have a number of potential applications which meet and go beyond the original TDS design parameters. Many of these are detailed in the *TDS Final Report* (see Vaughan, et al., 1989), and other TDS documentation (see *TDS User Guide*, etc.). Some of the advanced potential applications were outlined in earlier chapters, as they relate to current AFHRL R&D projects. Additional possible applications not in the present AFHRL research program are noted below.

7.1 Current and Future Research on Training Management Issues

By its very nature, the TDS involves the quantification of training requirements, and any research or development efforts in the area of improving Training Management or decision making are potential applications for the TDS technology. A number of studies of Air Force training have indicated major problems and need for improvements. In describing the current training management system, Johnson and his coworkers note that there are considerable constraints on improvements of Air Force training management. These include "system fractionalization," unpredictable production goals, "vague assessment measures," and limited investments in training resources (Johnson, Green, Soldwisch, Turner, and Wall, 1989:51-52).

One of the joint ATC-HSD projects to improve Air Force Training Management is the Advanced Training System (ATS), a computer-based management system which will automate most training management functions and facilitate the flow of information among ATC organizations. The present ATS design, however, does not include sufficient advanced training decisions support technology to solve some of the present major problems.

HSD commissioned a study to identify areas of potential improvement in Air Force training management. Some of the priority needs identified in the HSD study include:

> 1. An algorithm to constrain and objectively prioritize training requirements in the MAJCOMs could both reduce the personnel energy expended and enhance the requirement screening responsiveness.
>
> 2. Models and data flows to improve Manpower, Personnel, and Training (MPT) issue leverage, accuracy, and timeliness in acquisition planning would directly impact mission readiness with new systems.
>
> 3. Systems for accurate officer and pilot selection and classification would reduce recruiting efforts and pipeline through-put.

4. Development of job specific task baselines for military, OJT, and aircrew instruction would ensure war-fighting competencies and dampen much of the inefficient perturbations in instructional goals.

5. Objective measures for performance assessment for rated and enlisted personnel would enable managers to demonstrate impacts from changes in training system operations and increase training effectiveness.

6. A system to quantify, capture, and articulate total resource costs for training would support a resource conservative stabilization in the training system across the USAF.

7. Consolidation and automation of OJT record keeping would decrease supervisor diversion of effort and increase quality time with apprentices.

(Johnson, Green, Soldwisch, Turner, and Wall, 1989:51-52)

In a second volume of the HSD study, Johnson and his co-workers recommend an integrated strategy to identify technological "shortfalls" needed to remedy major training management problems in the "21st century environment." They observe:

> An examination of current and planned USAF research activity that is relevant to training management against the system needs reveals several shortfalls in reaching desired system capabilities. Most notable needs are the US Air Force-wide general data base network, a single task list development system, a dynamic job survey system, hierarchical task structure system, an integrated physiological-psychological student selection system, and a total USAF costing system.

(Johnson, Damewood, and Turner, 1989:52)

Clearly, several of these areas are ones where the TDS R&D has already made some significant progress. Comprehensive reports of the TDS R&D were not available to Johnson and his coworkers at the time of their study. Several of the areas they suggest are also ones where advanced TDS work could be beneficial. As noted in the last chapter, however, such advanced research needs to be very carefully integrated so that R&D outcomes can be easily operationalized and research results can be made synergistic.

The TDS could be a key part of this advanced training decisions support system; it has the necessary capabilities for AFS modeling, assessment of planned changes, and evaluation of total AFS training costs and OJT capacities. No other system yet has such capabilities. Linked with AOTS and the performance measurement methodologies developed by AFHRL, TDS could provide part of the foundation needed to considerably enhance Air Force managers' capabilities for efficient, well-integrated MPT decision making.

7.2 New Weapon Systems Acquisition Process

One area which deserves special comment is that of estimating new MPT requirements for new weapon systems under development. TDS could be particularly useful in determining and costing alternative ways to meet training requirements for such systems. This adaptation for Training Decisions Technology will require additional development effort, but would bring the considerable advances made in the TDS R&D to bear on this problem area.

Currently, McDonnell Douglas has an Internal Research and Development (IRAD) effort underway in the potential application of TDS technology for the new weapons system acquisition process. Results to date suggest that some new techniques will be required for the prediction of allocation curves from known or estimated task (task module) characteristics, since no SMEs with experience in training the new weapon system would be available as a data source. This and other predictive issues are presently being studied, and one effort is currently underway to determine whether realistic predictions of Task Module allocation curves can be achieved.

While significant technological development issues are involved, work to date suggests that TDS technology can be meaningfully applied in the new weapons systems acquisition area. Thus, this is an area where significant additional R&D investment appears worthwhile.

7.3 Training Decisions Technology for Other DOD Agencies

Another major potential application for Training Decisions Technologies may be in the other military services and related DOD agencies. Since most of the other services and agencies have task-based job analysis systems, the foundation for the application of TDS technology exists. In addition, the present interservice training programs may provide the vehicle for adapting and extending TDS technology to examine interservice issues. The present TDS focuses attention on just Air Force-funded training; however, given access to appropriate MPT and cost information from the other services, it should be possible to utilize TDS technology to estimate interservice training costs and to model job and training flow patterns as well.

The basis for such extension may already exist in the form of interservice occupational analysis projects conducted jointly by the Air Force, Army, and Navy. Interservice and joint occupational projects have been completed for a number of areas (computer operators and programmers, explosive ordinance disposal, cooks and bakers, etc.); such joint efforts have created a situation where compatible data collection formats and joint analysis procedures are already developed. Thus, this cooperative network could be used for administration of new task characteristic data and U&T pattern information, rather than having to establish an entirely new system.

Some new technologies would need to be developed to insure the compatibility of occupational data and to reconcile differences in data collection techniques and procedures. Such new technological development would be minimal, however, because of the close compatibility of the existing interservice programs.

7.4 Training Decisions Technology in the Civilian Sector

Business and Industry are now becoming conscious of the tremendous dollar investment they have been making in on-the-job training programs, which heretofore have largely been hidden costs. The Training Decisions Modeling technologies could be applied quite cost effectively wherever a large corporation or other organization has a well developed task-based job analysis data base, preferably one where CODAP or ASCII CODAP processing are available.

In a broader context, the type of occupational modeling developed for TDS could be applied fairly efficiently wherever sufficient job analysis and training data are presently available. There is sufficient generality to this approach to decision making that it could be realistically applied almost anywhere that appropriate data could be gathered (any large industry, union, educational institution, etc.). Furthermore, the TDS as a decision support system, is a very positive model for other human resources management decision making.

8.0 CONCLUSIONS AND RECOMMENDATIONS

This examination of the technologies involved in the proof-of-concept Training Decisions System research and development suggests that it is a well-developed, viable decision support system (DSS) with significant potential applications not only for training decision making but also to the broader arena of MPT modeling and policy decisions. However, based on the sensitivity analyses and exercises of the system, there remain a number of areas within the present TDS design where additional development and refinement are needed to fully exploit its potential. Some recent findings from other R&D efforts might also be integrated to form the basis for an integrated MPT modeling capability. In addition, further exploratory R&D would be worthwhile to help us fully understand the significant analytic and decision support potentials of this system.

8.1 TDS as an Integrated Training Decision Technology

The TDS proof-of-concept system appears to have successfully integrated several rather disparate technologies (operations research modeling, occupational analysis task clustering and specialty analysis, cost accounting and prediction, etc.) into a coherent and serviceable training DSS. The independent technologies are in and of themselves significant contributions to the state-of-the-art in their respective areas; however, their integration into a single operating system provides training decision makers with a more comprehensive data analysis capability than has previously been available. For the first time, we can develop a realistic estimate of the total annual costs of training (including OJT) in a specialty and assess the capacity of representative units (organizations) to conduct training.

One of the most significant lessons learned from this R&D project was the need for a comprehensive "model" of each occupation (Air Force specialty) to insure a common understanding among decision makers as to the jobs and training programs of the AFS. Such a model must be comprehensive in its coverage of jobs and training programs, yet simple enough to be easily understood and manipulated. It must present a dynamic picture of the occupation, one which represents the flows of individuals through jobs and training states over the full span of their careers.

In the proof-of-concept TDS design, this need for comprehensive yet dynamic modeling was successfully met, yet its ability to portray the intricacies of the more complex specialties varied depending to the degree of complexity of the AFS model. We do not yet know the "optimum" level of detail for representing the more complex specialties (in terms of the number of Task Modules or the number of jobs needed to capture the essential elements of the AFS). Further R&D is recommended to vary these aspects of TDS models in order to determine the most appropriate level of analysis for critical decision making.

In addition, further refinement of data gathering is required. Various data collection efforts in the proof-of-concept TDS R&D project varied in the degree of success in capturing needed data. In particular, some of the most innovative data collection efforts, such as the

Resource Requirements Survey and Resource Availability Survey, were constrained in terms of time and development effort possible at that stage of the project. Yet these data elements proved to be among the most critical elements in predicting total training costs and the capacities of representative units to conduct on-the-job training. Thus, we recommend that these data collection instruments and procedures be targeted for further improvement.

8.2 TDS & STATE-OF-THE-ART SCIENCE

A review of the technologies involved in the TDS in terms of their relationship to state-of-the-art developments of several scientific disciplines indicated that some TDS technologies are extremely innovative. Indeed, several of these areas (such as dynamic occupational modeling) have potential applications which go well beyond there use in support of training decision making. Perhaps the most innovative aspect of the TDS proof-of-concept R&D was its integration of several independent technologies into a single decision support system. The success of this type of integration suggests that other state-of-the-art technologies might also be added to future TDS improvements to take advantage of new techniques and data bases. The modular design of the proof-of-concept TDS will greatly facilitate such integration of new developments.

In some cases, the TDS requirement for new technology and procedures has resulted in the development and refinement of other systems which go well beyond the original TDS requirement. One example of this is the task clustering technology developed in the AFHRL refinement of ASCII CODAP, where an advanced capability now exists for the identification and interpretation of inherent task clusters (modules). Since this new technology was developed after the point in time where it might have been used in the TDS R&D project, such new techniques have not yet been fully tested as to their utility for supporting new TDS studies. We recommend that any future TDS R&D include provision for testing the usefulness of the new ASCII CODAP technologies for identifying and interpreting task modules. In addition, other recently-developed technologies need to be monitored for potential applications in future TDS development.

8.3 POTENTIAL INTERFACE WITH OTHER R&D PROJECTS

The possible interaction and integration of the TDS technology with other AFHRL R&D projects were examined in some detail. The conclusion drawn from this examination was that several of these R&D efforts have the potential of enhancing TDS operations and, conversely, TDS has potential value for those projects. Some type of systematic interface needs to be developed where procedures and data derived in one AFHRL project can find immediate application in other R&D efforts. TDS might be used or adapted for a variety of purposes involving the modeling of Air Force specialties. There is also a need to examine the potential of TDS for use as a basis for integrating a number of these MPT research initiatives into a comprehensive MPT modeling system.

8.4 TDS EXERCISES

One of the major efforts under the present tasking was to exercise the system and its software to insure proper operation and to identify needed improvements in software and procedures. The system exercise was a very successful undertaking and a number of problems were identified and corrected. However, not all of the improvements in product formats and subsystem programs could be completed within the framework of the present project. We recommend these improvements be included in any future TDS R&D project.

8.5 TDS DOCUMENTATION

Another major effort under the present tasking was the redevelopment and refinement of TDS documentation. The *TDS Procedural Guide: TDS User Instructions*, August 1988, was separated into two volumes: the *TDS User Manual* and the *TDS Programmer Guide*, both dated 1 November 1989. In addition, to satisfy a need for concrete examples to support both of these procedural guides, a third and fourth volume of *TDS Examples* were developed which include examples of data collection instruments (*Examples* - Volume 1), TDS data files, runstreams, products and reports (*Examples* - Volume 2) for both a Current U&T Pattern and one Alternative U&T pattern. This compilation of materials represents an extremely complex and comprehensive portrayal of what the TDS is and how it operates.

These revised TDS documents should prove to be useful in communicating the structure and operation of the TDS to potential users and other interested parties. These volumes have already been used by staff members of Search Technology, Inc., of Norcross, GA, as a basis for developing a computer-based TDS tutorial (demonstrator) system. This tutorial is aimed at providing potential TDS users with an automated way to learn about the TDS at their own pace, with assistance provided (via menu selections) for additional explanations or discussions as needed. Under an extension to the present task order, members of the TDS R&D team provided assistance to the Search Technology staff in reviewing their TDS data displays, providing definitions and examples of analysis outcomes, and offering suggestions for improving the tutorial displays.

8.6 SENSITIVITY ANALYSES

In general, the results of sensitivity analyses conducted under the present tasking were highly satisfactory (as discussed earlier in Chapter 6). The system was found to be relatively insensitive to variability in random number streams and to two- and three-way interactions among variables. This provides some validation for the approach taken to the simulation of specialty job and training flows and the quantification of AFS training requirements. It also suggests that further sensitivity analyses could focus on main effects and thus more input variables could be assessed economically. The present sensitivity analyses looked at seven of the most important TDS input variable classes. The TDS model has many other input variables which may be important. We recommend that future TDS sensitivity analyses focus on main effects and that additional variables be studied.

8.7 ADDITIONAL TDS R&D

Based on the results of this review of TDS technologies, the sensitivity analyses, and exercising of the system, several additional R&D efforts appear worthwhile. These include additional work to validate allocation data (and curves), as well as some assessment of potential data bias. One tasking in the present project was to complete preliminary research plans for both an allocation data validation study and a data bias assessment. These research plans provide details for these suggested studies as a next step toward improving the TDS data collection procedures and operational data bases. We recommend that these two studies be included in any future training decisions R&D at the earliest possible opportunity.

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